Emission Reduction Framework for Leucaena

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Emission Reduction Framework for Leucaena
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Executive Summary

Leucaena is a tropical legume pasture used in beef cattle grazing, in northern Australia. Leucaena is a beneficial pasture from a livestock performance perspective, supporting higher growth rates in young cattle, and has anti-methanogenic properties which reduce emissions for each kilogram of dry matter intake (DMI) consumed. Under commercial conditions, abatement potential is expected to be 10-20% and because of the high establishment costs, planted areas are likely to support only a fraction of the herd on grazing properties, resulting in incremental abatement opportunities which are commonly 1% to a likely maximum of about 5% of enteric methane per enterprise. Leucaena may also support higher soil carbon levels in pastures. Benefits associated with faster growth rate and soil carbon can be quantified through existing ACCU Scheme methods. This framework focused on quantifying the direct reduction in methane that can be achieved through grazing Leucaena, where there is no current ACCU Scheme method enabling quantification of abatement.

Research indicates the percentage of Leucaena in the diet can be used to calculate the methane abatement. Most formal carbon programs require validation of emission reduction technologies in order to quantify abatement. The purpose of this report is to provide an emission reduction estimation framework which could be adopted in the ACCU Scheme, or for the purpose of insetting.

Key technical features of framework

Abatement calculation requires quantification of DMI, and the fraction of Leucaena in the pasture. DMI is predicted from livestock numbers and performance. The livestock and pasture data can be summarised as in Table 1.

Table 1 Information required to predict methane reduction from Leucaena

Information	Units
Number of cattle grazed	No.
Live weight at start of grazing period	kg/head
Live weight at end of grazing period	kg/head
Days grazed	Days
Reproductive status	Proportion of animals pregnant, lactating
Dietary crude protein	%
Proportion of leucaena in the pasture	% of intake

Commercial scale abatement with Leucaena must focus on the practical minimum requirement to minimise costs. This framework has considered cost-effectiveness of implementation as a core aspect of the design.

The livestock data are reasonably easy to determine and collect, but the requirements of the method for livestock data will have a large bearing on the cost-effectiveness of maintaining the required records. There are also limitations around the auditability of these records, as they are difficult to collect in a way that can be accurately verified. The pasture data (crude protein and proportion of Leucaena in the diet) is relatively difficult to measure accurately, and may change in response to fixed attributes of the pasture, such as row spacing, and variable attributes, such as grazing frequency and grazing pressure. This makes direct measurement far more difficult. Thus, the central challenge in developing a suitable method is the quantification of Leucaena in the pasture that is consumed by cattle. We explored options that could establish the proportion of Leucaena in a given project in the first year, and treat this as a 'fixed' proportion in subsequent years to reduce compliance burden.

Proposed quantification approach
Stage 1: Determining the percentage of leucaena in a paddock could be achieved by various different options: Use satellite imagery to measure the total grazing area, excluding all non-grazing pasture objects (water, buildings, roads etc.) and then calculating the leucaena area based on the row spacing and size of canopy.

Stage 2: Now that the area of leucaena is known the next challenge is to determine the amount consumed in the diet of grazing cattle. There is no fixed ratio of Leucaena in the diet based on row spacing as this is strongly influenced by grazing pressure. Leucaena is favoured by animals and will be consumed at higher rates than the proportion of the pasture indicates, if grazing pressure is not too high. Quantifying Leucaena in the ration may be informed via regular sampling of pasture CP using Faecal NIR (F.NIR) and comparison with pasture benchmarks, and cross referencing this with records of cattle performance and stocking rates. This method, implemented in the first year, could enable a fixed ratio of Leucaena to be established within a target stocking rate range.

Stage 3: The final step is to apply the Stifkens *et al.* (2022) methane abatement calculation to determine the reduction in methane yield for the herd. This is then used to estimate the amount of CO_2-e avoided by cattle grazing the leucaena-grass pasture.

Table 2 proposes a series of options:

- Option 1 is to model using "full records" of animal movements (this would be the default approach, but it is expected to limit the cost-effectiveness of the method) and a comparison option.
- Option 2 would rely on paddock book records,
- Option 3 would rely on Remote paddock records.

Table 2. summary of the proposed series of methods, requirements and feasibility

Method 1 "Full records"	
Quantification of project area and mitigation rate potential	Satellite imagery to confirm planted area and row spacing. Canopy cover of leucaena is used to determine the percentage in the pasture. Livestock model of stocking rate and grazing days with cattle performance used to confirm leucaena in diet. Confirmed over first year with detailed livestock records of performance and with tool such as Cibo Labs pasture biomass (with high resolution satellite data) to confirm disappearance rate and stocking rate/intervals. After first year, % Leucaena inclusion becomes the fixed rate applied in the equation of Skifkens et al. 2022 to predict abatement using the equation 1.
Model input data required	Animal number onto paddock: Date, NLIS ID, weight Animal number off paddock: Date, NLIS ID, weight
Verification records	Satellite imagery – date and time stamp showing cattle entering and exiting paddock (within 5 day window based on available imagery). Livestock model of stocking rate and grazing days with cattle performance used to confirm leucaena in diet. Pasture biomass changes (confirmed with high resolution satellite data). Animal data. Preferably automated data download capability to third party.
Method benefits	High degree of accuracy (could be improved with higher resolution satellite images/LiDAR to determine biomass and change in biomass during stocking). Will report total emission reduction.
Method limitations	High level of data required. Producers don't have weigh and scan facilities at gate to leucaena paddock. Leucaena areas would need single entry/exit point (may not be feasible when paddocks are large areas and stocking large numbers of cattle). Would be highly reliant on producer records. Would need some form of independent check – could possibly be supplied by a secure data management system or direct satellite datalink to a third party which is checked against satellite imagery taken on a regular basis with resolution sufficient to identify individual cattle.
Implementation	Could be delivered using BHM calculator with minor change to methane calculation method and assumed pasture CP.

Method 2 –"Paddock book records"	
Quantification of project area and mitigation rate potential	Satellite imagery to confirm planted area and row spacing. Livestock model of stocking rate and grazing days with cattle performance used to confirm leucaena in diet. F.NIR results over a year confirm the % of leucaena in the diet for the pasture. After first year, % leucaena inclusion becomes the fixed rate applied in the equation of Skifkens et al. 2022 to predict abatement using the equation 1.
Model input data required	Paddock book records of animals onto paddock Date, head number, description, estimated weight Animals off paddock: Date, head number, description, estimated weight
Verification records	Paddock book supplied digitally (i.e. through program such as Agri-Webb) or manually (scanned records). Records available for audit and review. Livestock model of stocking rate and grazing days with cattle performance used to confirm leucaena in diet. Satellite imagery showing total hectares of pasture. Change in pasture biomass over a year to confirm leucaena consumption, as a standalone baseline year.
Method benefits	Relatively easy to do, no further equipment or few costs to implement and fairly small amount of time.
Method limitations	No way of tracking different groups of cattle if more than one group is brought onto the paddock, which makes it far more difficult to accurately track animal performance (mob averages may mask individual animal performance). No robust way of confirming weight or weight gain beyond an estimate. Would not be sufficient for EI calculation. May possibly be acceptable for total emission reduction but difficult to provide assurance.
Implementation	Could be delivered with simple calculation tools.

Method 3 – Remote records	
Quantification of project area and mitigation rate potential	Satellite imagery to confirm planted area and row spacing. Canopy cover of leucaena is used to determine the percentage in the pasture. Livestock model of stocking rate and grazing days with cattle performance used to confirm leucaena in diet. F.NIR results confirm % in diet. Confirmed over first year with detailed livestock records of performance and with tool such as Cibo Labs pasture biomass to confirm disappearance rate and stocking rate/intervals. After first year, % leucaena inclusion becomes the fixed rate applied in the equation of Skifkens et al. 2022 to predict abatement using the equation 1.
Model input data required	Satellite imagery and possibly video imagery of paddock gates to count livestock movements on/off and provide first-order confirmation of livestock weights.
Verification records	Satellite imagery and video imagery at paddock gates. Livestock model of stocking rate and grazing days – growth rate and mitigation rate.
Method benefits	Third party verifiable data Requires very little additional labour after set up
Method limitations	Relies on consistent satellite and video. Relies on robust ability to count livestock and estimate weight/weight gain from video Relies on ability of satellite to confirm livestock are not moved off the area via other gate ways. Will have set up costs and possible maintenance issues to deal with for cameras. Technology would require once-off research to confirm it can achieve acceptable degree of error.
Implementation	Relies on technology capability to be confirmed (further research needed)

Barriers to entry

Leucaena has been shown to have other productivity and land management benefits including increased cattle productivity and profitability, improved communal pasture quality, control of dry land salinity and protection against erosion. However, the area sown to Leucaena is only a fraction of the total potential area and the major hurdle is cost-of-establishment. Establishing an abatement method, particularly in the context of the proposed Integrated Farm and Land Management (IFLM) method may provide incentive to expand the area of Leucaena, which should be considered additional.

Barriers associated with an abatement method revolve around assessing and verifying leucaena consumption at scale and minimising the cost of collecting and verifying livestock data. Conceptual and technically feasible options have been presented. The resolution and time delay of satellite imagery needs to be sufficient to assess the leucaena pasture.

Hypothetical case study

The following tables present a summary of the case study and the potential methane abatement based on percent of leucaena in the diet.

Location	Central north Queensland
Rainfall (annual long term average)	600 mm
Pasture system	Leucaena – grass system
Baseline land use	Grazing-finishing
Leucaena pasture	Double row with effective row width of 1.5m. Interrow spacing at 4 metres.
Pasture management activities	Rotational grazing and paddock spelling to allow leucaena pasture to regenerate to full canopy cover before stocking. Walk over weighing system fitted to measure weights of cattle in and out of the paddock. Cattle graze for 180 days. Stocking rate is ~1.5 AE/ha. 1000 head grazed.
Total area (ha)	700
Canopy cover (at peak) (ha)	175
Quantification method	Area of pasture and Leucaena measured using Google Earth. Full automated process possible with NDVI with high resolution satellite data and calibration and testing of deep learning model.
Livestock parameters	NILS data collected of cattle moving on and off the paddock to confirm date and walk over weigh data to log weight and weight gain.
Leucaena % in diet	35
Abatement (tCO_2-e) (5% discount)	570
Potential ACCU revenue (assuming $40/ACCU)	$22,800

Conclusions and Recommendations

Leucaena is a promising option for reducing emissions from northern beef herds. The relatively modest commercial use currently implemented, compared to potential, indicates this pasture system could be considered additional when new areas are developed. Major commercial barriers to adoption relate to establishment costs.

Leucaena is a relatively low abatement pasture and in high-compliance systems such as the ACCU Scheme, the major barrier to adoption will be compliance costs. Uptake will be greatly enhanced if compliance burden can be minimised and this is vital for the success of the method.

We outlined robust methods here (for example option 1) but we expect these would not be adopted because of the compliance burden. On the other hand, option 3 has promise because it could substantially reduce compliance burden, but further research would be beneficial to confirm if it can deliver acceptable accuracy in the abatement estimates. Considering short term imperatives for emission reduction and the limited options available to most northern livestock managers, we recommend method development with the enabling options included (option 3) in parallel with further research to support the rigour of the livestock records and Leucaena inclusion rate assumption. Ongoing focus on cost-effectiveness will be key to achieving practical outcomes that enable livestock producers to abate emissions using Leucaena and these learnings will support other pasture or forage based abatement.

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1 Introduction

The Australian agricultural sector occupies a prominent position in the context of climate change impacts and opportunities. Producers within this sector contend with some of the most challenging environmental conditions globally, including prolonged droughts, intense flooding, wildfires, and disease outbreaks, all of which exert significant influence on farm production and income levels. ABARES estimates that climate change impacts caused a loss of more than 23% of potential profits (an average of -$29,200 per farm per year) across the agriculture sector from 2001-2020 (Hughes *et al.*, 2022). The sector, in response, is demonstrating a commitment to adaptation and innovation, bolstering resilience, and making investments in the potential of a low-emissions future. Nevertheless, there is a recognized imperative for an expedited transition. Given the ongoing evolution of climate patterns and the heightened frequency and intensity of extreme weather events, a shared dedication to collaborative and innovative solutions remains a critical aspect of the sector's journey forward.

The Australian Government has set specific emissions reduction targets: a 43% decrease from 2005 levels by 2030, with a long-term goal of achieving net zero emissions by 2050. In line with this, all state and territory governments have pledged to attain net zero emissions by 2050 or earlier, with many of them establishing interim targets. This collective effort reflects a more ambitious approach to reducing emissions across Australia, necessitating comprehensive actions throughout the economy. Importantly, the agricultural sector in Australia will play a vital role in achieving these targets. To lower emissions in agriculture, it is imperative to sustain ongoing mitigation efforts, employ innovative technologies, and incentivise carbon abatement.

In the face of escalating environmental challenges, including climate change and biodiversity loss, there is an urgent need to develop innovative frameworks that encourage carbon sequestration and responsible environmental management by landholders. To date, carbon sequestration methods developed by the Australian Government have certain limitations which represent a barrier-to-entry for land managers who may otherwise participate in carbon sequestration projects. Given the expansive area occupied by grazing enterprises in Australia and the substantial emissions arising from livestock, this sector offers significant potential for large scale carbon abatement. As such, there is a need to devise strategies aimed at incentivizing responsible land and livestock management practices while simultaneously minimizing the obstacles that may hinder participation in emerging ecosystem service markets. This effort seeks to strike the balance between encouraging sound land and livestock management practices and ensuring sustainable agricultural production.

This report aims to identify and address existing gaps in accessible method options by conceptually developing a novel approach that can bridge these gaps, ultimately expanding opportunities for landholders to engage in carbon markets. A key consideration is the potential attractiveness of a method that utilises a high performance tropical legume for livestock emission mitigation. The framework has been developed with a view to harnessing this opportunity, specifically with leucaena.

This report will not only delineate the conceptual foundations of the framework but will also outline limitations and research gaps.

1.1 Existing ACCU Scheme Method Limitations

The Australian Carbon Credit Units (ACCU) Scheme, formerly known as the Emission Reduction Fund (ERF), constitutes a voluntary initiative encouraging the adoption of practices and technologies for emissions reduction and carbon sequestration. It plays a pivotal role in incentivizing landholders, communities, and businesses to undertake projects that mitigate greenhouse gas emissions or sequester carbon. Enacted through various federal legislation, such as the *Carbon Credits (Carbon Farming Initiative) Act 2011* and the *Carbon Credits (Carbon Farming Initiative) Rule 2015* (Australian Government, 2023a; Australian Government, 2023b), the ACCU Scheme allows participants to earn ACCUs, where each ACCU represents one tonne of carbon dioxide equivalent (tCO2-e) emissions stored or avoided (Clean Energy Regulator, 2023).

This scheme provides opportunities for farmers, including graziers, to actively engage in emissions reduction efforts and sequester carbon. Participants implementing approved ACCU methods can accrue ACCUs, tradable units that can be sold to generate income streams through market sales. ACCUs can be sold, either to the Australian Government through a carbon abatement contract, or to private buyers (such as businesses seeking to offset emissions). As such, the ACCU price is set by the market demand and supply. Despite fluctuations in its value, the accrual and selling of ACCUs continues to be a profitable endeavour for eligible landholders who successfully implement ACCU Scheme projects. The economic returns from these projects may arise from selling ACCUs, and/or by using the ACCUs to offset the emissions of a company to produce ‘carbon neutral’ projects. Typically, these economic returns incentivise carbon abatement by offsetting potential losses in productivity that may be associated with carrying out the project. The projects can also generate more market appeal for a company’s product through socially responsible practices (i.e., carbon abatement), justify higher produce prices, and diversify income. The ability for primary producers to access this market has led to genuine, largescale, and additional carbon abatement together with positive environmental outcomes.

In this context, a "method" refers to the specific types of projects undertaken to decrease emissions and earn Australian carbon credit units (ACCUs). These methods provide detailed instructions on how to conduct project activities and measure the resulting reduction in emissions. Essentially, a method serves as a legislated set of instructions for achieving emission reduction goals and earning carbon credits. There are numerous methods available under the ACCU Scheme, with opportunities for industry and the land sector. Within opportunities for the land sector, there are agricultural methods, savanna burning methods, and vegetation methods.

There are many potential methods to reduce enteric methane emissions in the herd on a per head basis and thereby reduce the intensity of methane production per 1 kg of beef product. These include changing feed type (e.g. from pasture to concentrate feed or to new pasture varieties); use of supplements that reduce methane emissions (fats, oils, plant extracts and nitrate); improving productivity through management change including use of growth enhancers and improved genetics; immunisation against methanogens and selective breeding of animals with low methane emissions, through either reduced feed intake per product or reduced methane production per feed consumed, without compromising production characteristics (Wall *et al.* 2010; Jeyanathan *et al.* 2014; Belanche *et al.* 2020). However, currently, only two methods exist to generate ACCUs via reducing emissions from beef cattle, i) the Beef cattle Herd Management Method (Australian Government 2017) (abbreviated here as "BHM") and ii) the "Feeding nitrates to beef cattle method". A third method, the "reducing greenhouse gas emissions by feeding dietary additives to milking cows was previously developed but is now closed. The BHM method enables producers to reduce emission intensity and monetise this by comparing a baseline emission intensity with a project emission intensity. The Nitrates method operates by enabling producers to feed nitrate in place of urea, to achieve direct reductions in enteric methane from cattle consuming the product.

No other methods currently exist that enable producers to quantify and potentially monetise emission reductions from livestock under the Australian ACCU Scheme.

Leucaena has anti-methanogenic properties resulting in lower methane emissions per kilogram of feed intake for cattle consuming leucaena compared to other pastures. As a side benefit, leucaena also improves livestock weight gain and has been used in Queensland as a grazing legume to a relatively limited extent, compared to it's potential. Expanding leucaena use is a potential means for the livestock industry in northern Australia to reduce emissions.

Leucaena may help reduce emissions via multiple mechanisms. Cattle tend to have faster weight gain on leucaena than grass pastures, reducing the emissions of these cattle (Harrison et al. 2015). This benefit can be realised via the BHM. Leucaena may also support higher soil carbon sequestration (Conrad et al. 2017) and potential soil carbon benefits can be realised via the Soil Carbon ACCU Scheme method (Australian Government 2015). However, abatement via the direct reduction in methane per head per day or per kilogram of DMI consumed has not been included in an ACCU scheme method, and the method for inclusion of this emission reduction in carbon neutral programs is also unclear. This report outlines a framework for quantifying this form of abatement, specifically from leucaena.

1.2 Background on leucaena

Leucaena is a commercially available sub-tropical legume with broad adoption across Queensland. Currently, leucaena is grazed in Northern Australia cattle regions. *Leucaena leucocephala ssp. glabrata* was developed in Queensland by CSIRO as a highly nutritious forage for cattle in the 1960s. Since then, there have been various new cultivars that have improved yield, establishment rate, disease and pest resistance, and have reduced weed potential (Walton 2003).

Currently, leucaena is mostly grazed in Northern Australia, predominantly Queensland cattle regions. Estimated plantings were 250,000 hectares in QLD prior to 2016 (Burgis 2016). A detailed survey of lands was completed by Beutel *et al*. (2018) examined larges areas of Central/southern Queensland using a novel technique to quantify the leucaena cultivation on grazing lands. This has been the most accurate estimate of leucaena coverage completed to date and determined that there were 123,500 ha of leucaena in the central/southern Queensland study area (Beutel *et al.* 2018). There is significant potential to expand leucaena, considering that there is an estimated 13.5 million ha of area in Queensland suitable for expansion (Beutel *et al.* 2018), suggesting leucaena use is not currently widespread and should still be considered 'additional' if new land areas are planted. Barriers limiting the expansion include the slow establishment rate, psyllid insect sensitivity and toxicity to cattle.

Pasture production systems are of lower quality in northern Australia compared to southern systems, resulting in low performance in cattle and increased methane production over the lifetime of the animal. Improved pasture options are a mechanism that could increase the growth rates and herd productivity (including better reproductive efficiency) of northern herds (Gardiner and Parker 2012), which would indirectly help to mitigate emissions. Peer-reviewed research has shown tropical legumes have the potential to combine these productivity gains with reductions in enteric methane emissions (Shelton *et al.* 2021; Stifkens *et al.* 2022) and the sequestration of carbon in soil (Conrad *et al.* 2017). For example, steers can reach 600 kg live weight on leucaena 6 – 12 months earlier than those on straight buffel grass (Shelton *et al.* 2021).

Leucaena has multiple benefits, including:

i) Stifkens et al (2022), among others, reported cattle produce around <10% (~20% leucaena diet) and up to 40% (~35% leucaena inclusion) less methane per grazing day while on leucaena compared with grass or other legumes (though as yet carbon credits can't be earned from this benefit)
ii) Leucaena improves cattle growth rates, allowing faster turnoff and allowing lower stocking rates (or more cattle) in the supply chain.

iii) Leucaena has been shown to increase soil carbon sequestration by increasing pasture growth and providing more nitrogen in the system. In higher rainfall areas the sequestration rates are quite substantial.

iv) Leucaena is currently available and in use commercially at small scale.

1.3 Background on methane production in cattle

Methane is a potent greenhouse gas with a global warming potential (GWP) 28 times that of carbon dioxide (CO_2). The ability of ruminants to digest and ferment plant biomass and rumen degradable protein largely depends on the complex microbial community that reside in their rumen. Ruminal methane production is the result of the biochemistry of feed fermentation by the microbial community in the rumen. Hydrogen (H_2) and (CO_2) produced during the process of ruminal fermentation are the major substrates used by methanogens, which are the direct methane producing organisms in the rumen (Greening *et al.* 2019).The reduction methane emission from livestock a crucial aspect of mitigating climate change from the agricultural industry.

Enteric methane, which is methane produced in the rumen via process called methanogenesis, which accounts for majority of all the methane produced by the animal (Knapp *et al.* 2014). Most of the enteric methane is produced in the rumen and released by eructation (> 80%), and the remainder produced in the lower digestive tract. Enteric methane released by ruminants constitutes a loss of energy contained in the feed. Methane production is correlated with dry matter intake (DMI) which is used as an indicator to predict methane emissions in the herd. Charmley *et al* (2016) demonstrated that for that each kg of DMI, livestock generate on average 20.7 g of methane for forage-based diets. There is a relationship of live weight gain and intake of leucaena. Optimal levels of leucaena are at ~35% of diet to achieve ~1kg/day liveweight gain (Shelton *et al.* 2021). However, voluntary intake of leucaena varies from 5 – 100%, which can be managed by adjusting stocking rate and percentage of forage dry matter (Shelton *et al.* 2021).

2 Quantifying Emission Reduction from forages

Extensive research into anti-methanogenic forages in Australia has identified a large number of legumes, grasses and herbs that produce bioactive compounds which can reduce enteric methane emissions (Beauchemin *et al.* 2008; Eckard *et al.* 2010; Badgery *et al.* 2023). Studies have also shown that legumes increase animal productivity due to higher crude protein and feed digestibility, which leads to increased liveweight gain and decreased turn-off age thereby lowering the lifetime emissions of the animal.

Two major legume options have emerged for northern beef production, leucaena and Desmanthus. Recent animal trial results support the conclusion that leucaena has demonstrated greater and more consistent abatement potential compared to desmanthus. The initial work by (Suybeng *et al.* 2020) observed a reduction in methane yield when desmanthus was fed with poor quality grasses. However, a follow up study determined that desmanthus does not reduce methane emissions in cattle on high-quality diets (10% CP, 68% NDF) (Suybeng *et al.* 2021). In their work, methane emissions and methane yield measurements were taken of beef cattle that had been supplemented with both good quality lucerne and poor-quality hay with increasing levels (0%, 15%, 30% and 45% DMI) of different desmanthus cultivars. Average daily feed intake was lower in the 30 and 45 % desmanthus diets, compared to the 0% treatment. Methane produced was correlated to DMI and the methane yield increased with higher percentage of desmanthus in the diets (Suybeng *et al.* 2021). The conclusion that desmanthus does not reduce methane emissions seems to contradict previous studies (Vandermeulen *et al.* 2018) and although differences in study methodology and plant composition may explain the variation between the studies, the results highlight that more research is needed to determine the anti-methanogenic properties of desmanthus.

A key industry report finding concluded that desmanthus in the diet showed no conclusive evidence of methane abatement, with one study indicating a diet comprising of 30% desmanthus would reduce methane yield by 10% when the diet was low nutritive quality (5 – 8% crude protein) but subsequent trials with higher nutritional value diets showed no change in methane yield, leading to the overall conclusion the abatement potential varies according to the nutritive value of the accompanying forages, with additional studies needed to fully understand the relationship (Charmley 2020). Furthermore, Charmley (2020) reported that when the basal ingredient was hay there was a linear reduction in methane emissions as the desmanthus inclusion in the diet increased from zero to 31%.

For comparison, multiple *in vitro* studies have shown that leucaena has more consistent methane abatement potential. Leucaena fed to cattle at 44% of the diet showed an 18% methane abatement (Kennedy and Charmley 2012). Leucaena included in sheep diets also reduced methane emission (Archimède *et al.* 2016). Leucaena which was investigated for its potential to reduce GHG emissions on northern Australian beef cattle farms (McSweeny and Tomkins 2015). The results from their study showed steers grazing on leucaena had lower daily emissions than those grazing on grass pastures with values of 95±7.9g head^{-1} day^{-1} compared with 132±7.1 g head^{-1} day^{-1} for native pasture, resulting in a 28% methane abatement (Conrad *et al.* 2017). A recent study of key importance by Stifkens *et al.* (2022) showed a significant reduction in methane in cattle yield when the companion forage was poor-quality. A simple dose response algorithm for calculating avoided emissions was established thereby allowing a method to measure the methane reduction in herds grazing leucaena pastures.

Leucaena contained secondary plant compounds called condensed tannins (Shelton and Dalzell 2007). These tannins are linked to reduced CH4 emissions/kg digestible DM intake and per kg animal product. Leucaena contains a significant amount of CT tannins (33 to 61 g/kg DM) (Tan *et al.* 2011) and a high protein content 200 to 250 g/kg DM.

Studies have discussed the role of tannins in mitigating methane production in the rumen. Tannins are polyphenolic compounds that have the ability to form complexes with dietary proteins, minerals and polymers hemicellulose, cellulose, pectin, thus inhibiting digestion which confers tannins with their anti-nutritive property that may explain why some legumes offer better growth compared to others (Waghorn *et al.* 2006). The anti-methanogenic activity of tannin-containing plants has been credited to the condensed tannin group because hydrolysable tannins are more toxic for the animal. However, some researchers have found no indication of tannin concentration influencing the methane production, showing that further work is needed to fully understand the role of plant secondary compounds in reducing methane production (Charmley 2020). Stifkens *et al*. (2022) suggested that tannins were responsible for most (67%) of the observed reduction in methane yield from leucaena.

It is important to make note of the status of leucaena in the research to date. Although equations have been developed to determine the relationship between the inclusion of leucaena in the diet to methane yield, no equations exist that demonstrate the relationship between the active ingredient and methane yield. Such a relationship has not been defined to date as there is not currently a simple method for linking the active ingredient of these legumes to mitigation. Consequently, prediction methods rely on the simple relationship of amount of leucaena in the diet and the associated emission reduction, based on peer reviewed research (CH_4 g/kg DMI^{-1}). The study by Stifkens *et al*. (2022) on the effect of leucaena on methane production in beef steers provided the following equation (equation 1) for prediction of emissions from leucaena included in the diet between 0 and 48%.

Equation 1. $y = -0.09x + 19.8$

Where:

- y = CH_4 yield (g kg DMI^{-1})
- X = *Leucaena* inclusion in the diet (%)
-

Table 3 Calculated % methane reduction based on leucaena in the diet (Stifkens *et al.* 2022)

% in sward	% methane reduction from baseline
0	0
18	15
36	20
48	22

The linear relationship described by Stifkens et al. (2022) indicated the yield of methane drops by 0.09 g/kg DMI. Although the relationship was linear, there was evidence that a 36% inclusion rate was optimal in terms of both animal performance and methane emissions. The research concluded that the anti-methanogenic effect of tannins, accounted for two-thirds of the methane reduction, with improved diet quality accounting for the other third. Though tannins may not completely explain the methane mitigating properties of leucaena and other bioactive compounds may have contributed to reducing methane production (Stifkens *et al.* 2022).

2.1 Practical considerations and limitations

Practical considerations and limitations involved with leucaena are well known, see (Dalzell *et al.* 2006; Shelton *et al.* 2021) and include:

- Establishment is expensive and can be hit and miss depending on season – drought and establishment failure is the greatest risk.
- Up-front investment is substantial and the payback is long-term.
- Sufficient information exists around pasture production and cattle performance, though there is more information needed on the carbon sequestration potential, methods to quantify stocking potential and grazing yields to help guide management.
- Leucaena can spread and become an environmental weed leading unwanted ecological changes. The industry has already addressed this concern with methods in-place to reduce the change of weeding and there is on going research to develop a sterile cultivar to eliminate the issue.
- Research is yet to characterise the active anti-methanogenic compounds in leucaena though tannins have been suggested as the compounds involved (Stifkens *et al.* 2022).

- Future research would need to consider the methane yield differences of different cattle breeds, age and type, the leucaena varieties and the companion grasses and other legumes as this could influence the methane production.

These limitations suggest that support via an ACCU Scheme method may enhance uptake and would meet the requirements for additionality.

3 Framework for Leucaena

3.1 Conceptual Development

Conceptually, the research indicates that prediction of methane reduction from grazing leucaena can be achieved provided the amount or proportion of leucaena consumed by cattle is known. Table 4 shows the key information required for an abatement method based on the proportion of leucaena in the pasture.

Table 4 Information required to predict methane reduction from Leucaena

Information	Units
Number of cattle grazed	No.
Live weight at start of grazing period	kg/head
Live weight at end of grazing period	kg/head
Days grazed	Days
Reproductive status	Proportion of animals pregnant, lactating
Dietary crude protein	%
Proportion of leucaena in the pasture	% of intake

This information can be divided into two types: livestock data and pasture data. The livestock data is reasonably easy to determine and collect, but the requirements of the method for livestock data will have a large bearing on the cost-effectiveness of maintaining the required records. There are also limitations around the auditability of these records, as they are difficult to collect in a way that can be accurately verified. The pasture data (crude protein and proportion of leucaena in the diet) is relatively difficult to measure accurately, and may change in response to fixed attributes of the pasture, such as row spacing, and variables, such as grazing frequency and grazing pressure. This makes direct measurement far more difficult. Thus, the central challenge in developing a suitable method is the quantification of leucaena in the pasture that is consumed by cattle.

3.2 Exploring livestock performance as a means of quantifying Leucaena intake

Some researchers have identified a causal relationship between live weight gain and intake of leucaena in topical mixed sward pastures. In addition, the amount of leucaena in the diet linearly increases with the time spent grazing leucaena (Shelton *et al.* 2021). Cattle will favour leucaena over other forage when it is plentiful in the pasture, though the consumption level decreases as grazing continues and the amount of leucaena in the pasture depletes. Stocking rates are higher for leucaena - buffel grass systems, with irrigated pastures stocking 4 AE/ha (Shelton and Dalzell

2007). It is commonly reported that a steer needs to consume 35 - 40% of leucaena in its diet to gain 1 kg/head/day, though this can vary with seasonal changes (Dalzell *et al.* 2006). At a herd level, cattle consume around 20% to 40% of their diet as leucaena when on the pasture. Grazing is typically limited to <30% of dietary intake to minimise mimosine toxicity (Dalzell *et al.* 2012; Shelton *et al.* 2021). This rate of consumption has been reported by many. Bottini-Luzardo *et al.* (2016) showed that leucaena represented an average of 34.2% of total DM consumed. Shelton (2021) showed a relationship with live weight gain and leucaena intake where optimal levels of leucaena are at ~35% of the diet to achieve ~1kg/day liveweight gain. To achieve this, the crude protein content needs to be 12-13 % in the diet, which can be achieved with leucaena pastures but not grass only pastures (Shelton and Dalzell 2007). A poor crude protein content (~5%) with 36% leucaena in the diet showed a gain of 0.46 kg/head/day with a 20% methane abatement (Stifkens *et al.* 2022). Although the daily gain was lower than 1kg/head/day it was positive and higher than on grass alone. Cattle breed, type and age would influence the rate of consumption as well as the available biomass of leucaena in the pasture. The higher performance of cattle when supplied with Leucaena is a potential source of information to validate inclusion rates. However, to provide a robust indicator this would need to be compared to a baseline or comparison that was determined in the same region and season. This was not seen as suitable for validation, but can be seen as useful supporting information.

3.3 Exploring the relationship between row spacing and Leucaena intake

Row spacing affects the proportions of leucaena and grass forage available. Wide spacing (15m) decreases the proportion of leucaena, narrow spacing (5-6m) increases it (Shelton *et al.* 2021). Closer row spacing may ensure sufficient supply of leucaena is available thereby increasing the period during which high rates of gain are achieved (Charmley *et al.* 2023). A recent grazing trial over 24 weeks with a set stocking rate of 1.3 AE/ha on a leucaena/grass pasture at a row spacing of 12m, with an average leucaena percentage of 6.5% in the paddock (initially ~10% declining to 0.2% after 24 weeks) showed that livestock consumed on average 35% leucaena in their diet over the trial period. Initially the inclusion was 60% when leucaena availability was high and cattle showed a preference consuming leucaena over pasture and had high weight gain ~1.45 kg/head/day. The researchers reported that the leucaena paddocks were unable to support the high rate of weight gain and at the mid point of the 24 week trial the intake had declined to 30% and then further to 15% at the end of the trial (Charmley *et al.* 2023). Parallel to this, rates of weight gain also declined from ~1.45 to 0.42 kg/head/day, as nutritive value and leucaena availability declined (Charmley *et al.* 2023). The results indicate that the row spacing and percentage of leucaena in the trial pasture alone was not sufficient to support a consistent rate of leucaena in the diet for the 24 week trial.

3.4 Exploring faecal NIRS as a means of quantifying Leucaena intake

At an individual level, cattle will consume leucaena at different volumes and the amount and quality of the diet selected by cattle on leucaena pasture can be determined by scanning faeces using a calibrated near infrared spectroscopy (F.NIRS) (Coates and Dixon 2007; Dixon and Coates 2008). The F.NIRS method analyses the C_3/C_4 ratios (C3 and C4 plants) in the sample and is not specific to leucaena. However, the F.NIRS method provides an option to validate the proportion of leucaena (as non-grass proportion of diet) in the diet as well as CP, nitrogen and other parameters. Symbio Laboratory and Gcology Data Services are two laboratories certified to perform the test. F.NIR data from a representative sample set of the herd would be indicative of the percentage of leucaena in the diet across the whole herd. Representative samples would need to be collected over the year and an average would need to be determined. This could be done in the first year of the project.

3.5 Modelling options

Abatement requires modelling of emissions based on livestock numbers and performance. Establishing a series of norms regarding stocking rate and animal performance would support validation, by confirming (or questioning) the abatement based on the biophysical attributes of the herd. For example, in normal seasons growth rates on Leucaena should be 0.7 to 0.9 kg $head^{-1}$ day^{-1} compared to 0.5 kg $head^{-1}$ day^{-1} on comparison, grass only pastures. Failure to demonstrate higher livestock performance could indicate insufficient Leucaena in the diet and act as a trigger for further investigation of the performance of an abatement project.

3.6 Barriers to entry

Leucaena is a relatively low abatement technology. The major hurdle to overcome in establishing this method is minimising the compliance cost of implementing a low-abatement method.

Conceptual and technically feasible options have been presented. The following research is needed to bridge the gap to implementation and resolve the scalability issues.

1. Establishment costs and ongoing maintenance costs are the major commercial barrier to expansion of leucaena. It may be possible that added income from carbon projects could improve cost-effectiveness and stimulate more planting activity.
2. Digital connectivity will support more farmers to transition to precision farming tools, which can help them manage inputs, improve productivity, minimise environmental impacts. Uptake has been hindered by rural infrastructure limitations such as lack of rural broadband and 4/5G accessibility.
3. Development of cultivars suitable for conditions in other regions with improved psyllid resistance.

4. Satellite resolution needs to be sufficient to determine the leucaena coverage and track cattle movements. Obtaining high resolution, up-to-date satellite data or LiDAR measurements for biomass calculations is currently both expensive and time consuming.
5. An automated assessment of satellite imagery involves data acquisition, storage and interpretation solutions, the costs of this would need to be investigated.
6. In regard to assessing the livestock, the installation of walk over weighing systems with standard test weights requires reliable power (solar power) and connection to a data network (4G/5G) capable of sending the data. Several companies offer products with this capability but it is an added cost.

3.7 Research and development priorities

Research and development priorities to further progress the framework and understanding and technological gaps include ways confirm canopy cover of leucaena using low-cost satellite data. Expanding on this would be to investigate ways to automatically identify and count livestock numbers using satellite data. Low cost and easily implemented ways of video counting livestock and measuring the weight of livestock on/off paddock. Widespread rollout and ease of implementation would require ways to integrate the whole system and a detailed cost-benefit (including establishment and ongoing maintenance) analysis to determine the economic viability of method.

3.8 Case Study

The case study considered a property in Central Queensland with steers grazing a leucaena-grass system. Details are summarised in Table 5. The cattle graze the leucaena pasture for 180 days as part of a growing and finishing phase before being transported to market. Satellite data of the block was viewed and the area, row spacing and canopy cover of the leucaena was confirmed (Figure 1).

Table 5 hypothetical case study summary

Framework	Leucaena emission reduction
Location	Central far north Queensland
Rainfall (annual long term average)	600 mm
Pasture system	Leucaena – grass system
Baseline land use	Grazing-finishing
Leucaena pasture	Double row with effective row width of 1.5m. Interrow spacing at 4 metres.
Pasture management activities	Rotational grazing and paddock spelling to allow leucaena pasture to regenerate to full canopy cover before stocking. Walk over weighing fitted to measure weights of cattle in and out of the paddock. Cattle graze for 180 days. Stocking rate is ~1.5 AE/ha. 1000 head grazed.
Total area (ha)	700
Canopy cover (at peak) (ha)	175
Percent of leucaena in the diet	35%
Quantification method	Area measured using Google Earth. Full automated process possible with NDVI with high resolution satellite data and calibration and testing of deep learning model.
Livestock parameters	NILS data collected of cattle moving onto pasture to confirm date and walk over weighing to log weights in and out of pasture.

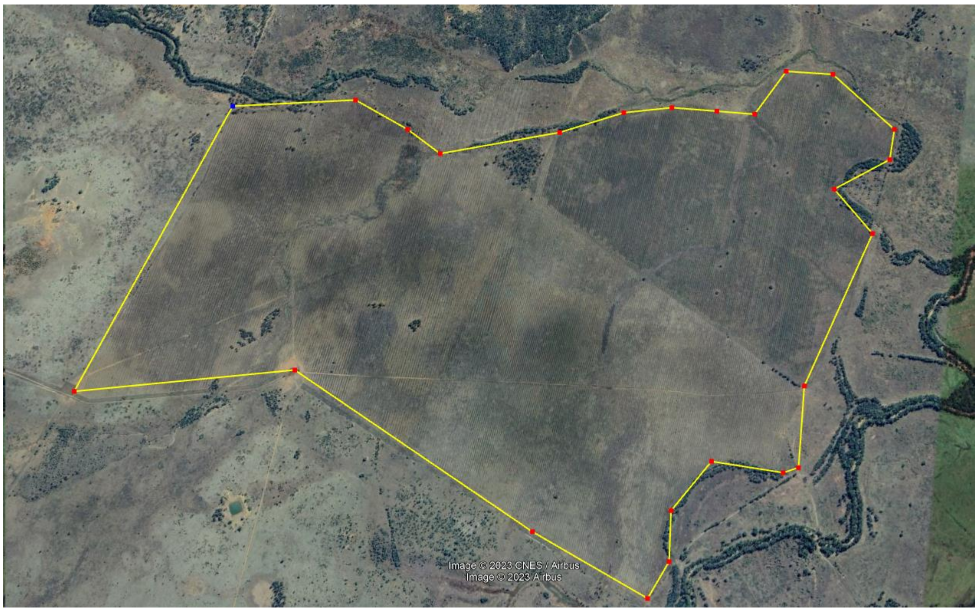

Figure 1 700 ha block of leucaena, measured 6m inter-row spacing, 2m canopy.

The estimated methane abatement has been calculated on the average (35%) leucaena in the diet, showing the potential reduction in methane is 18% (based on interpolation of model equation 1) (Figure 2).

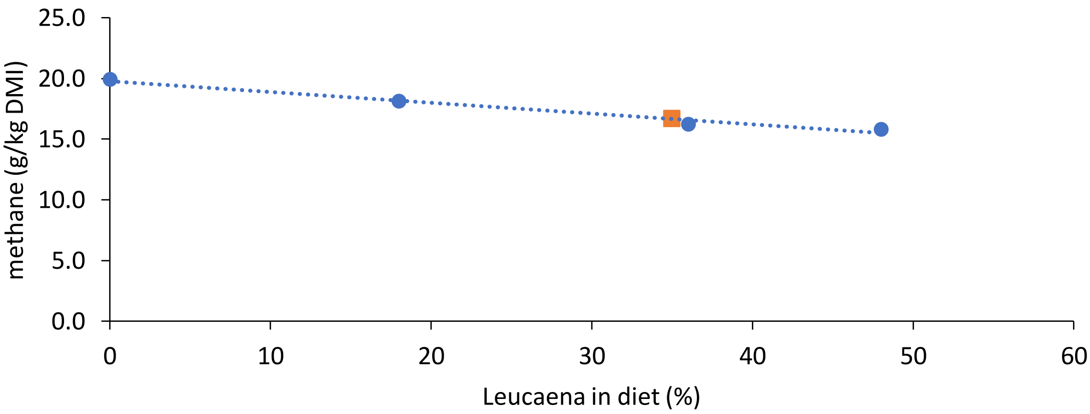

Figure 2. Reduction in methane yield when leucaena is included in the diet. The orange square indicates the estimated methane reduction for 35% leucaena inclusion

A summary of the leucaena case study results is provided in Table 6. As part of a sensitivity analysis, if the leucaena inclusion rate was 18% the abatement would be 504 tCO_2-e and if the inclusion rate was 45% the abatement would be 609 tCO_2-e. ACCU yields may include discounts to account for uncertainty in the method and therefore may be lower than the abatement. This requires further consideration to determine the degree of uncertainty in the methods proposed. For indicative purposes, the financial return from an ACCU Scheme project with the attributes of this case study, and with a 5% discount, were in the order of $22,800 per year.

Table 6 Summary of the leucaena case study results

Parameter	Leucaena (35%)	Buffel only
Head grazed	1000	1000
LW start (kg/hd)	420	420
LW close (kg/hd)	550	550
Days grazed	180	265
LWG (kg/hd/d)	0.72	0.49
Whole herd GHG emissions (tCO_2-e)	849	1449
Abatement (tCO_2-e) (less 5% discount)	570	0

4 Conclusion and Recommendations

Leucaena is a promising option for reducing emissions from northern beef herds. The relatively modest commercial use currently implemented, compared to potential, indicates this pasture system could be considered new and additional when new areas are developed. Major commercial barriers to adoption relate to establishment costs and any ongoing maintenance of the pasture.

Leucaena is a relatively low abatement pasture and in high-compliance systems such as the ACCU Scheme, the major barrier to adoption will be compliance costs. Uptake will be greatly enhanced if compliance burden can be minimised and this is vital for the success of the method.

We outlined robust methods here (for example option 1) but we expect these would not be adopted because of the compliance burden. On the other hand, option 3 has promise because it could substantially reduce compliance burden, but further research would be beneficial to confirm if it can deliver acceptable accuracy in the abatement estimates. Considering short term imperatives for emission reduction and the limited options available to most northern livestock managers, we recommend method development with the enabling options included (option 3) in parallel with further research to support the rigour of the livestock records and Leucaena inclusion rate assumption. Ongoing focus on cost-effectiveness will be key to achieving practical outcomes that enable livestock producers to abate emissions using Leucaena and these learnings will support other pasture or forage based abatement.

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