final report

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Innovative livestock systems to adapt to climate change and reduce emissions

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Executive summary

We have demonstrated that sheep produce less methane from some pasture species than others. Biserrula reduces methane emissions more than other legumes when fed to animals in the animal house and this effect is greater when it was fed as fresh pasture compared to hay. Our results from testing different legumes in the laboratory reflected these results in the animal house, but we did not find a significant direct reduction in methane emissions in the field. The most consistent, key, driver of methane and animal productivity in this project, was pasture quality. High digestibility and low fibre feed reduced methane yields and methane intensity and increased productivity. We have some evidence that a "choice" pasture can improve rumen efficiency compared to ryegrass pasture alone, which was reflected in higher daily live weight gains in the sheep, but not in methane intensity. In addition, legume-based pastures provide an option to increase growth rates and decrease methane emissions (total and emissions intensity) during a period when perennial ryegrass pastures are declining in nutritive value. Our greatest challenge has been to demonstrate the differences we predicted from the laboratory and animal house experiments in grazing animals. We think the variability in timing of grazing and grazing behaviour of animals prior to measurement may well be masking the differences that exist in the field.

Our results show that farmers should be able to make better choices of pasture species to reduce emissions and emissions intensity in grazing livestock without reducing productivity, but that it is difficult to demonstrate the effects on methane emissions in-field. The clearest message for producers and policy makers is emphasising the importance of managing pastures and grazing techniques to maintain the highest quality of feed, because it improves rumen efficiency and animal productivity and ultimately improves emissions intensity. The bio-economic modelling showed that the critical control points that would provide the largest industry gains (eg. lamb survival, survival post-weaning) were traits that could be influenced by genetic selection and improved feed management. Based on the results and modelling in this project it is possible that a systems-based methodology, similar to the beef cattle herd management method that uses change in emissions intensity multiplied by level of production as the basis of calculating the reduction in emissions, could offer the potential for sheep farmers to be involved in the ERF and to concurrently increase profit. The difficulties we faced in demonstrating the reduction in emissions we predicted should occur in the field based on our animal house work, means there are three main questions that remain only partially answered; 1) does Biserrula have the potency to reduce methane emissions in commercial farming scenarios; 2) can a "choice" pasture reduce methane intensity and; 3) what is the ability of Biserrula to reduce methane emissions while maintaining animal performance when used as a "choice" pasture. We are confident that the different effects that pasture species are having on methane emissions are real, but more work needs to be done in the methodology around determining those effects in-field.

Table of Contents

1. Background

The Filling the Research Gap program funded research into emerging abatement technologies, strategies and innovative management practices that reduce greenhouse gas emissions from the land sector (without reducing production); increase soil carbon; and enhance sustainable agricultural practices.

A practical way to adapt to climate change and reduce methane emissions is to modify the forage base and breed sheep that are more resilient to the environment and produce less methane. In two environments (Western Australia and Victoria), this project quantified the productivity of legume pastures with lower *in vitro* methanogenic potential. It also focussed on pasture species that were expected to have an extended growing season, as extra growth in early summer has a high economic value. In addition to conventional mixed pastures, sheep also grazed a “Choice” pasture of adjacent monocultures of ryegrass and subclover so the animals could optimise diet selection. Spatial separation of pastures should enable species-specific management of individual components to increase overall production. It should also enable utilisation of novel legumes that have low methanogenic potential but do not persist well in mixed pastures, especially under more variable climatic conditions.

Aims

A practical way to adapt to climate change and reduce methane emissions is to modify the forage base and breed sheep that are more resilient to the environment and produce less methane. Our aim in this project was to examine the potential impacts of a range of sheep and pasture management strategies on whole farm profit, risk and methane emissions in two environments (Western Australia and Victoria). This included testing legume species that are known to have antimethanogenic effects (eg. Biserrula) or species in monocultures, or in combination, with the potential to improve production efficiency in the lab, animal house and in-field. It was expected that sheep offered the “choice” pasture would optimise diet selection and rumen function, which would improve feed use efficiency and reduce methane emissions. It was also expected that sheep offered monocultures of low methanogenic legumes would emit lower methane emissions without compromising production.

The production and emissions data generated in this project was modelled to determine the impacts of a range of sheep and pasture management strategies on whole farm profit, risk and methane emissions for different environments and climate change scenarios.

2. Methodology

Activity 1: Methane and animal production from pastures varying in methanogenic potential

Experimental design

Feed intake, live weight change, methane production and rumen fermentation products were measured from individual sheep fed at 1.2 times their maintenance metabolisable energy (ME_m) requirements on freshly cut pasture under animal house conditions for four weeks. Pasture treatments included; ryegrass (*Lolium multiflorum* cv. Robust); bladder clover (*Trifolium spumosum*); subterranean clover (*Trifolium subterraneum L* cv. Dalkeith); french serradella (*Ornothopus sativas* cv. margurita); and Biserrula (*Biserrula pelecinus* cv. casbah). Sheep (10 to 12 per treatment) were housed in individual pens at the animal house facilities at CSIRO Floreat, Perth, Western Australia (31°56'57.16"S 115°47'19.69"E, elevation 16 m). Sheep were housed in one of eight respiration chambers for 23 h to determine daily methane emissions from air subsamples, which were analysed by gas chromatography in real-time.

Pastures

Pasture plots of about 1ha each were grown in sandy soils at The University of Western Australia Shenton Park Field Station (31°57'00.53"S 115°38'68"E, elevation 15 m) and at Murdoch University (32°04'19.23"S 115°50'11.96"E, elevation 24 m). Pastures were direct drilled into a prepared seedbed without fertilizer in mid-June 2013. Legumes were planted at the rate of 20 kg/ha after inoculating with Alosca (*Rhizobium* Groups C and BS). The legume swards were top-dressed with Super: Potash 3:2 at the rate of 150 kg/ha. During establishment, all plots were fertilised with nitrogen at 23 kg/ha (urea) and SuperPhos (CSBP: P 9.1, S 10.5, Ca 20 w/w %) at the rate of 125 kg/ha. Once established the legumes were fertilised every 3-4 weeks with super: potash 3:2 (CSBP: P 5.5, K 19.8, S 6.3, Ca 12 w/w%) at 125 kg/ha. Weeds were controlled in pastures by spraying with Fusion®/super (320 g/ha) and by hand pulling. Infestation of red-legged earth mites was observed and Le-mat® (100 mL/ha) was applied to control populations.

Pastures were cut each morning (approximately 13 weeks after sowing) using a 135 degree adjustable fitted hedge trimmer (Stihl HL-KM 135). The cut pasture was raked into plastic tubs and stored in a mobile cool-room before transporting to the animal house. Grab samples of individual pastures (about 50 g) were collected daily immediately before feeding in the animal house and stored at -20 °C before drying in an oven at 60 °C for 72 h then ground through a 1 mm sieve. Pasture nutritive values were assessed by wet chemistry using methodology detailed in AFIA Laboratory Methods Manual (2011): acid detergent fiber (CSL method LMOP 2-1108), acid detergent lignin (CSL method LMOP 2-1111), crude protein (AOAC 990.03, method LMOP 2-1124), dry matter digestibility using the pepsin-cellulase method 1.7R (AFIA 2011, method LMOP 2-1128); crude fat by petroleum ether extract (CSL, method), neutral detergent fiber (CSL method LMOP 2-1107), cold water soluble carbohydrates by water extraction with benzoic acid and using the alkaline ferricyanide decolouration method 1.11A (AFIA 2011, method 2-1103). Metabolisable energy was predicted using the equation ME (MJ/kg DM) = 0.203 DOMD (%) - 3.001 (AFIA 2011, method 2.2R based on PC DOMD method LMOP 2-1124), where DOMD is dry organic matter digestibility. Bomb calorimetry was used to determine gross energy values (CSL method LMOP 2-1118) and digestible energy was predicted using the equation DE (MJ/kg DM) = Gross energy x dry matter digestibility (%).

Sheep and feeding

Merino ewes (13 to 15 months of age; live weight 44 kg +/- 4.6) were acclimatised to a feedlot for 3 weeks before being assigned to five treatment groups (n=10 per group) by stratifying according to live weight and sire pedigree. The sheep were allocated to individual pens in the animal house based on their treatment group and using eight blocks of eight pens in an incomplete block design. The fresh pastures were offered once daily to the sheep at rates equivalent to 1.2 times ME_m requirements for 4 weeks (26 September to 25 October 2013). Feed quantities were calculated according to the Australian Feed Standards (Freer et al., 2007) using the live weight of individual sheep and the metabolisable energy estimate of the pasture. The amount of fresh pasture offered was based on the oven dry weight of pasture subsamples taken on the previous day and estimated metabolisable energy of the pasture. Feed intake was determined as the weighed amount of pasture offered less refusals. Live weight and body condition score were measured twice weekly. After four weeks of feeding fresh pasture methane was measured from individual sheep. The sheep were then returned to the animal house and offered a standard ration of oaten chaff and 10% lupins at 1.2 times ME_m containing; 289 g of acid detergent fiber; 664 g of digestible dry matter; 88 g of crude protein; and 8.59 MJ of metabolisable energy per kilogram DM. The sheep were fed the standard ration for 25 to 31 days before methane was measured again. The data collected from the standard ration phase was used as a covariate in the final analysis.

Respiration chambers and methane measurement

At the end of the pasture and covariate phases sheep were housed in open circuit respiration chambers for 23 h to determine methane production. Methane production was measured using eight respiration chambers over seven days with sheep allocated to chamber and day by matrix to account for variation over time. The room in which the respiration chambers were located was controlled at a temperature between 23 to 24ºC. The sheep were habituated to the chambers and monitored remotely while in the chambers as described by Bickel et al. (2014). Methane was quantified using the procedure of Klein and Wright (2006). Briefly, each sheep was placed in a Perspex chamber fitted with an extractor fan to pull a continuous flow of air through the chamber. The air volume was measured using a gas meter and a sample of the outgoing air was drawn continually by a diaphragm pump. A subsample of homogenized exhaust air was drawn continuously at about 3.9 mL/min thru 2.5 mm infusion tubing by 2 peristaltic pumps (Technicon III, Labquip, Markham, ON). Every six minutes a subsample of air was taken by peristaltic pump and fed into one of two gas chromatographers with a total of four gas chromatograph columns (Shimadzu (model GC 17) Scientific Instruments, Balcatta, Western Australia) equipped with flame ionization detectors, stainless steel columns 3.2 mm by 3.05 m packed with molecular sieve 5A, 80/100 mesh (Alltech Associates Pty Ltd, Balkham Hill NSW), and 4 Valco valves fitted with 1.0 mL sample loops. Nitrogen was the carrier gas (400 kPa head pressure) and oven and detector temperatures were set at 150 and 300 ºC, respectively. Methane output was calculated as STP air volume through the chamber/1000* corrected chamber methane ppm, where;

CH_4 g/day = litres per day/22.4*16;

STP (standard temperature and pressure) = pressure in the pipe* air volume through the chamber/absolute temperature of chamber air/1013.25*273.15;

Pressure in the pipe (mbar) = Atmospheric pressure – chamber pressure;

Air volume through the chambers (m^3) = Air volume (meter reading)/ minutes of sheep in the chamber;

Corrected chamber methane ppm = chamber methane – ambient air methane (using peak areas divided by 100,000*standard correction coefficients).

Methane production per unit of digestible energy is reported rather than per unit of metabolisable energy. Metabolisable energy calculations assume that losses of energy to methane and urine are 19% (Freer et al., 2007). However, in this instance actual losses to methane were measured and therefore digestible energy was more effective at explaining methane yield than metabolisable energy.

Immediately after exiting the respiration chambers and prior to feeding, rumen samples were taken from each sheep via a stomach tube using an electrical vacuum pump (CSIRO standard operating procedure C1). The liquid portion of the sub-samples was used to determine volatile fatty acid concentrations and ammonia as described by Durmic et al (2010). In brief, pH was measured and then sub-samples were aliquotted into appropriate eppendorf tubes. For VFA 0.2 mL of 1M sodium hydroxide was added to 1mL of rumen fluid, and for ammonia concentrations, 0.2 mL of 2M hydrochloric acid was added to 1 mL rumen fluid. All tubes were shaken by hand and placed on ice before freezing at -40°C.

Animal ethics approval for this study was by the CSIRO animal ethics committee, Floreat, Western Australia.

In vitro fermentation technique (IVFT)

Plant samples were harvested using hand shears from pastures assigned for use in the *in vivo* experiment. Each plant species sample (about 100 g wet weight) were placed in zip-lock freezer bags and frozen at –80ºC then freeze-dried for 7 days. All dried samples were ground through a 1 mm sieve, sealed in screw-capped plastic vials and stored at room temperature. An *in vitro* batch rumen culture system designed to mimic the rumen environment was used to test the ground plant samples for their methanogenic potential, as described previously (Durmic et al., 2010). Briefly, under anaerobic conditions 0.1 g of plant material was mixed with 10 mL of strained and buffered rumen fluid in bellco tubes. Sealed and crimped tubes were then incubated at 39ºC in a shaking incubator

(50 rpm) for 24 h. After incubation, rumen microbial fermentation was assessed by measuring gas pressure using a pressure transducer (Greisinger Electronic GmbH, Regenstauf, Germany) and methane production from headspace gas using a gas chromatographer (CP-4900 Varian MicroGC, Middelburg, Netherland).

Statistical analysis

Predicted means for all effects of forage treatments were generated and compared using Restricted Maximum Likelihood (REML) in GenStat 15th edition (VSN International 2012). Forage treatment, mean metabolic weight and the average daily methane per intake during the covariate period, plus all significant interactions were fitted as fixed effects while pen, respiration chamber number, and day were fitted as random effects. Log transformations were used when appropriate to normalise residual plots. Multiple linear regression was used to fit variance components to a prediction equation and generalised linear regression to determine the best model.

Activity 2: Methane and animal production from manipulating diet composition

The research agreement for this experiment states **“**Priority legume pastures from Activity 1 will be fed to sheep with varying proportions of grass”:

a) 100% ryegrass

b) 100% legume

c) 33% legume and 67% ryegrass and

d) 67% legume and 33% ryegrass.

We used hay chaff for this experiment for two reasons. First, pasture conserved as hay better represents the type of feed offered to sheep in Western Australia for a large portion of the year; and second, the difficulty of providing fresh pasture to sheep in the animal house during the summer/autumn period. This generated useful industry data and showed that the potency of Biserrula as an anti-methanogenic pasture may have been diminished by the process of conserving the sward to hay. It is likely that Biserrula contains volatile compounds that inhibit methane production and these compounds may have been lost during the sun drying process in the paddock. This theory is supported by our *in vitro* work, which showed that fresh Biserrula pasture dried in a freeze drier was more potent at reducing methane than the same material dried at 60°C in an oven (*in vitro* data available on request).

Experimental design and sheep

Feed intake, live weight, methane production and end products of rumen fermentation were measured from sheep fed 100% Biserrula (*Biserrula pelecinus L.*) chaff, 100% ryegrass chaff and two ratios of Biserrula:ryegrass chaff. Merino wethers (n=80) aged between 9 and 12 months were sourced from the Maternal Efficiency Flock (Rosales Nieto et al., 2013) at the University of Western Australia

Research Farm, Pingelly (32.5097°S, 116.9955°E). All sheep had full pedigree records and were selected according to their pedigree, health, live weight and condition score. For three weeks the sheep were offered a commercial pellet (10.3 MJ metabolisable energy, 14% crude protein) *ad libitum* and oaten hay while they acclimatised to the feedlot scenario. Forty one sheep were then selected with live weights averaging 40 kg ± 3 kg and transported to CSIRO (31.9380°S, 115.7940°E).

At CSIRO, the sheep were housed in individual pens, which were assigned according to treatment groups. The sheep were allocated to treatments by stratifying for live weight and sire. The treatment groups were then allocated to seven blocks of eight pens in an incomplete block design to optimise the comparisons of treatments within blocks of pens. Individuals were then fed at 1.3 times their metabolisable energy requirement for maintenance (ME_m) for 38 days. The diets fed were either 100% ryegrass; 67% ryegrass and 33% Biserrula; 67% Biserrula and 33% ryegrass; or 100% Biserrula, all offered as chaffed hay.

The amount of feed offered each day was calculated according to the Australian Feed Standards (CSIRO Publishing, 2007), with inputs including the live weight of individual sheep and the estimated metabolisable energy of the ration. Daily feed intake was determined by subtracting daily feed refusals from the amount offered and live weights were measured twice weekly. Sub-samples (approximately 50 g fresh weight) of ryegrass and Biserrula chaff were collected each day for the duration of the treatment period. The sub-samples were bulked at weekly intervals and the nutritional values were determined using near-infrared spectroscopy (NIRS) supported by wet chemistry analysis (CSIRO, Floreat).

Methane and measurement

Methane production for individual sheep was measured during the final two weeks of the treatment period using open-circuit respiration chambers for small ruminants (Williams, 2005). For methane measurement each block was allocated a chamber day and animals within pens allocated to a chamber within the day using a matrix that ensured that each treatment appeared at least once in each chamber across the days. At the end of the treatment period six sheep were measured in the respiration chambers each day. Sheep entered the respiration chambers at 0900 h and exited at 0800 h the next day. While inside the chambers sheep had access to water and their daily ration, and human access was limited to minimise disturbance to animals.

The method used to measure methane in the respiration chamber was described above in Activity 1.

Volatile fatty acid and ammonia concentrations

Rumen samples were taken from each sheep the day following the measurements of methane at the end of the treatment period. These samples were taken at around 10 am, approximately two hours after feeding. Samples were taken and processed as described in Activity 1.

In vitro fermentation technique (IVFT)

The method used was adapted from Activity 1, but for freeze-dried hay rather than fresh pasture and with the addition of subsampling of fermentation end products for VFA and ammonia quantification (method described in Activity1).

Statistical analysis

All statistical analyses were performed using GenStat (VSN International, 2012). Effects of treatments on feed intakes, live weights, rumen samples, and methane production were assessed using Restricted Maximum Likelihood (REML). Methane production and yield were fitted as fixed effects with treatment and/or different variaties and interactions where appropriate. Methane measurement day and chamber number along with sire were fitted as random effects. Methane yield was calculated from individual feed intake in the 24 hours prior to entering the respiration chamber, and feed intake and methane production while individuals were within the chamber for 23 hours.

Activity 3: Plot scale grazing trials 2014 and 2015

a) Western Australia

Experimental design

This was a spring-grazing experiment over 2 seasons (2014 and 2015) at The University of Western Australia Research Farm "Ridgefield", Pingelly, Western Australia (32.5097°S, 116.9955°E). In each year 240 dry merino ewes that were 14 months of age and weighing 50.6 kg (+/-8.2) were stratified for live weight and sire (based on estimated breeding values for methane emissions relative to live weight) to groups of 24. Each group was assigned to one of ten plots (1.5 to 3 ha/plot) with two replicates of five pasture treatments; annual ryegrass (ARG; *Lolium rigidium cv. robust*); subterranean clover (Sub; *Trifolium subterraneum L* cv. Dalkeith); side-by-side monocultures of ryegrass and subclover (Choice); serradella (Serr; *Ornothopus sativas* cv. margurita) and; biserulla (Bis: *Biserrula pelecinus* cv. casbah). The sheep grazed unrestricted feed on offer (FOO) in spring for 8 to 10 weeks over two seasons. Weekly measurements included; feed on offer; nutritive assessment of the pastures; and live weight and scoring of body condition. Methane emissions were determined fortnightly from individual animals using portable accumulation chambers (PACs).

Pastures

After soil analysis, lime was applied at 3 Tonnes/ha in November 2013 following the harvesting of an oats hay crop. Excess stubble was removed by grazing sheep and super: potash 3:1 was applied at the rate of 125 Kg/ha in April 2014 and 2015. Paraquat (135 g/L) was applied at the rate of 1L/ha to control volunteer oats and capeweed in 2014 and on 21st May 2014 plots were direct drilled without fertiliser using an Aitchison seed drill at the rates of; 25 (ryegrass and subclover), 15 Kg/ha (Biserrula and serradella); and 10 Kg/ha of the corresponding Alosca for each legume. Grass weeds were controlled using Haloxyfop (520 g/L) at 80-100 mL/ha and Redlegged Earth Mite (Halotydeus destructor) were controlled with Lorsban (chlorpyrifos) applied at 150 mL/ha. All pastures were re-sown on 9th May 2015 with the exception of subclover, which re-stablished from the 2014 seedbank. Ryegrass plots were lightly grazed by sheep in August of both years to promote tillering and to reduce biomass. Grazing by the sheep was deferred until September 1 in both years, which was when FOO reached *ad libitum* levels - at least 1200 kg DM/ha on all plots.

Sheep

The sheep were selected from the ‘Maternal Efficiency Flock’, which is maintained at Ridgefield. The Maternal Efficiency Flock is a self-replacing flock with pedigree records and breeding values on all animals. The feed efficiency and methane production has been measured post-weaning on all animals born since 2009. The advantage of using these animals was that previous measures of methane production and MY could be used to select a group of uniform animals, hence reducing between animal variations and increasing the likelihood of measuring detectable differences between pastures.

The ewes were acclimatised to pastures consisting of native grass, ryegrass and subterranean clover, and allocated to two replicates of five treatments resulting in ten groups of 24 sheep. Each group was stratified according to live weight and sire ranking, which was based on estimated breeding values for methane emissions relative to live weight. Consequently, each group consisted of 12 sheep each of high and low methane potential. The influence of pastures on methane was determined by measuring each animal within each plot using PACs.

Measurement of methane production using PACs

The sheep were acclimatised to the pasture treatments for 15-20 days prior to measuring for emissions of CH_4. Twenty four sheep at a time were transported to a measuring facility consisting of 24 PACs. The sheep were placed for 1 h in individual PACs made of clear polycarbonate with dimensions of 122 cm x 122 cm x 56 cm (Goopy *et al.* 2011). Self-adhesive high density foam rubber was fitted to the base the PACs, which were lowered by pulley over the sheep and on to level, compressed rubber matting overlaying particle board to create a sealed system. A thermometer was mounted in each PAC and temperature was recorded at 15, 30, 45 and 60 minutes. A 5 mm hole was drilled in the top of each PAC for gas sampling. The holes were plugged with duct tape after each sampling. The amount of methane in the exhaled air within each PAC was measured in parts per million at 15, 30, 45 and 60 minutes using a portable flame ionisation detector (Photovac MicroFID). Concentrations of CO_2 and O_2 were measured twice during the hour using a portable gas analyser (ADC SB 1000). After each sheep was removed an electric portable air blower was used to flush the residual gases from the PAC and the rubber matting was cleaned.

Methane was calculated using the formula;

CH_4 g / day at STP = (CH_4 L / day x STP factor x (16.04 / 22.4))

Where;

CH_4 (L / day) = (CH_4(ppm) – (background) x (volume of air in PAC) / time in the PAC (mins) / (1000x60x24) / 1000

STP = 273.1 / (273.1 + average PAC temperature) x (average PAC pressure kPa / 101.3)

Volume of air in PAC = volume PAC (819 m^3) – Live weight (kg); using the assumption that 1L = 1 Kg Live weight

Allocation of sheep to methane PACs

Each gas measurement period consisted of five PAC runs per day over two days and gas measurements were repeated approximately every 14 days. Within each group of 24, sheep were evenly split into an “A” or “B” sub-group balanced for high and low methane potential. The sheep were allocated to PACs using a matrix balanced for pasture type (1 to 5), replicate (1 or 2), day of measurement (1 or 2), time of day (runs 1 to 5), methane potential (high or low), and methane measurement (1 to 4).

The sheep were mustered into mobile yards located adjacent to the grazing plots and weighed and condition scored weekly. On methane measurement weeks, the sheep were weighed immediately before entering the PACs.

Pasture measurements

Feed-on-offer (FOO), pasture composition (% legume, grass and other species) and pasture height using a sward stick (height to the tallest plant) in each plot were estimated weekly by an experienced technician walking in a “V” transect and taking 30 visual estimates (approximately 1 estimate every 10 metres). At each sampling event the estimates were taken from within about a 0.1 m^2 area. The visual estimates of FOO (kg DM/ha) were calibrated each time by collecting plant material from ~ 30 x 0.1 m^2 quadrats cut to ground level using a knife. The samples covered the full range of FOO estimates and pasture species. The quadrat samples were checked for soil contamination before drying for ~ 72 h at 65°C to determine the dry matter (DM) content.

Pluck samples were taken weekly for nutritive analysis (~ 600 g wet material) and *in vitro* fermentations (~ 100 g). The pluck samples were taken randomly across each plot and adjacent to areas that had been recently grazed. Material for hand-plucking did not include weeds but was otherwise estimated to be representative of the material removed by grazing. The pasture quality samples were refrigerated immediately before weighing and drying in an oven for ~ 72 h at 65°C and re-weighing (samples for nutritive analysis) or frozen at -80C for freeze-drying (samples for *in vitro*) then ground through a 1 mm sieve using a Tecator grinder (Foss, Hillerød, Denmark). The material was then stored at room temperature in sealed containers until analysis. Samples were analysed by Near Infra-red Spectroscopy (NIRS) (CSIRO, Floreat). Spectra were collected using a Unity Spectrastar 2500X rotating top window system (Unity Scientific). The spectrum file data from the Spectrastar was converted to a multifile for the chemometric software package Ucal (Unity Scientific) used to generate predictions. Ten percent of samples scanned by NIRS were set aside for chemical analysis and used to expand a Southern feed base equation and validate the calibration. Chemical analysis included; dry matter digestibility (DMD) and total ash using a modified Klein-Baker pepsin cellulase digestion (unpublished) corrected for *in vivo* using AFIA (Australian Fodder Industry Association) *in vivo* standards; neutral detergent fibre (NDF) and acid detergent fibre (ADF) (Ankom 200/220 fibre analyser; Ankom Technology Co., Fairport, NY, USA); crude protein (CP) was calculated as N × 6.25 and metabolisable energy calculated as (Sum(0.172*DMD value)-1.707.

In vitro fermentation technique (IVFT)

The method used was adapted from the method described in Activities 1 and 2 using fresh pasture samples taken weekly from all plots.

Statistical analysis

Effects of treatments on methane production were determined on GenStat (VSN International, 2012) using Restricted Maximum Likelihood (REML). The model used to explain variance in methane production (g/day at STP) used live weight at methane measurement as a fixed effect with combinations of pasture nutritive values as additive fixed effects. Random blocking was fitted as the random effect and consisted of individual pasture plot, sheep within plot, date of methane measurement, methane run within date of methane measurement, and PAC box and methane run within date of methane measurement.

b) Victoria

One-hectare areas of four forage systems were established near Hamilton in south west Victoria between spring 2013 and autumn 2015. Each forage system was replicated 3 times. The forage systems consisted of arrowleaf clover (Trifolium vesiculosum cv. Zulu), lucerne (Medicago sativa cv. SARDI 7 Series II), perennial ryegrass (Lolium perenne cv. Avalon), and a choice system, consisting of 0.5 ha monocultures of arrowleaf clover (cv. Zulu) and perennial ryegrass (cv. Avalon) arranged side-by-side. Sheep were offered free choice of the two forage types in this system.

One hundred and ninety two dry maternal composite ewes (2013 born, 64 ± 2.1 kg LWT, 3.8 ± 0.3 BCS) were allocated to each of the four forage treatments (16 ewes/ha) at the start of November 2015. Following 1 month of adaptation to pastures, methane was measured 3 times over the remainder of the grazing period (11 November 2015 to 7 January 2016).

Live weight and body condition score were measured at the start of the grazing periods and following each methane measurement point. Eye muscle area and fat depth were measured using ultrasound scanning at the start and end of the grazing period. Methane emissions were measured using the portable accumulation chamber (PAC) technique described by Goopy *et al*. (2011) with modifications. PACs were sealed using a water bath and the concentration of methane (CH4), carbon dioxide (CO2) and oxygen (O2) was measured at 15 minute intervals for 45 minutes. The concentration of methane was measured using a laser detector (Gazomat Inspectra laser, Bischheim, France), whilst CO2 and O2 concentration were measured using an infra-red gas analyser (Gas Data GFM Series, Coventry, United Kingdom).

Estimates of feed on offer (FOO) were performed weekly over the grazing period using a calibrated visual estimate. This included separate estimates of FOO for each of the monocultures in the 'choice' arrangements. Separate 'toe-cut' samples were collected at each of the methane measurement time points for assessment of nutritive characteristics. Samples were analysed by NIR at DEDJTR Horsham for dry matter digestibility (DMD), metabolisable energy (ME), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and water-soluble carbohydrate (WSC).

To minimise the effect of diurnal patterns on methane emissions, the order in which an animal's emissions were measured were analysed to account for sampling order. Analysis of FOO, pasture nutritive characteristics and animal live weight was undertaken using restricted maximum likelihood (REML) with a variance-covariance structure to account for repeated measurements over time. Data was transformed (Ln(x)) where required. Finally, REML was used to fit the various methane analyses with live weight (at time of methane sampling). Variance accounted for was calculated from the estimated variance components derived using REML analysis. All statistical analyses were performed using GENSTAT (VSN International 2012).

Activity 4: Wholefarm Systems Modelling

Background

The modeling we have completed in Activity 4 includes a pre-experimental analysis and an analysis based on attempting to ground truth the model using results that were generated within this project. Enteric methane emissions from sheep contribute approximately 2% of Australia's national greenhouse gas emissions. This indicates that there could be potential for sheep farmers to contribute to reducing national emissions by participating in the Emissions Reduction Fund if an approved method was developed. If a method was developed, farmers and their advisers would need to prioritise the management they would implement to reduce emissions and emissions intensity. Prioritising would require an understanding of the capacity to change and the impact of the different management strategies and technologies on both profitability and the level of emissions and emission intensity.

The pre-experimental analysis reported here tested the hypothesis that on-farm decisions can be prioritised using knowledge of potential production gains and bio-economic modelling of control points to calculate impacts on profitability and emissions. This analysis was carried out in two parts and the control points selected represented the different areas in which on-farm management could be directed to improve emissions. First, an analysis of the on-farm increases in profitability and emissions from increasing each of these control points was carried out using MIDAS (Kingwell and Pannell 1987). The second component quantified the potential industry gain in each control point and combined this and the MIDAS-calculated values to determine the total industry potential.

In the ground truthing analysis, on-farm implementation of new animal and pasture systems requires an understanding of their impact on profitability and their integration with the rest of the farm system. The MIDAS suite of wholefarm bio-economic models was used to evaluate low methane sheep genotypes and annual legumes that have low methanogenic potential. Production data for the animal and pasture productivity was based on measurements made in the on-farm component of this project.

a) Phase 1 - Pre-experimental analysis: modelling critical control points

MIDAS, model-farm, standard soil, pasture and flock characteristics

An existing MIDAS model for south-western Victoria was used in this analysis (Young et al. 2010, 2014). The model represents a ‘typical’ 1000-ha pasture only farm in the Hamilton region in south-western Victoria (36°58′S, 141°17′E), with an average annual rainfall 686 mm and break of season in the first week of April. The three land-management units on the model farm are as described in Young et al. (2010) and the standard level of pasture growth rate achieved is as described in Young et al. (2011). The flock type evaluated as the standard was a self-replacing flock based on a medium-wool genotype with lambing in August–September and shearing in March. Surplus ewes (culled for age or surplus young ewes) were mated to terminal sires to lamb in July–August and finished first-cross lambs were sold in December–January. A summary of the genotypes is provided in Table and a summary of the prices used in this analysis are provided in Table.

Table 1. Summary of the productivity of the ewe flock (2-, 3-, 4- and 5-year old)

Parameter	Unit	Value
Ewe Wool Production		
Clean fleece weight	kg	3.8
Fibre diameter	µm	19.1
Standard reference weight		
Merino breed	kg	52
Terminal Sire breed	kg	65
Weaning percentage		
Merino breed	%	83
Terminal Sire breed	%	88

Table 2. Meat, wool and grain prices used in the analysis

Parameter	Description	Unit	Value
Meat	Finished lamb	AU$/kg	5
	Cull adult ewes 5.5yo	AU$/head	80
	6.5yo	AU$/head	75
	Surplus young ewes	AU$/head	114
	Shipping wethers (17 months)	AU$/head	91
Wool	19 µm	AU$/kg clean fleece	13.90
	21 µm	AU$/kg clean fleece	11.75
Grain	Barley	AU$/t fed out	275

Calculation of emissions

The total greenhouse emissions for the sheep flock were included in the model using the relationships developed by Blaxter and Clapperton (1965) for enteric methane emissions and the relationships reported by the National Greenhouse Gas Inventory Committee (AGO 2005) for nitrous oxide emissions from urine and methane emissions from manure. Enteric methane emissions comprise the majority of the sheep enterprise emissions and they are controlled by the quantity and quality of the feed eaten.

Several metrics for methane emissions were calculated for the farm, including total emissions and emissions intensity. Emissions intensity is a measure of the level of emissions per unit of product, and the sheep enterprise is producing a dual product both meat and wool. In this analysis we report emissions intensity per kilogram of meat and wool combined (EIM+W). The unit of meat production used was kilograms of liveweight sold and the unit of wool production used was kilograms of greasy wool sold. These units were used because they are direct measures of the amount of produce leaving the farm and will be most easily collected by farmers engaging in the ERF.

The on-farm analysis

MIDAS was used to determine the change in emissions and profitability of the farm systems when each of the control points was increased by 1 unit while the others were held constant. It was assumed that the management changes or production changes could be achieved with no additional cost other than costs associated with managing and feeding the extra animals. That is, the analysis included any costs associated with an altered flock structure or altered number of sheep carried or the extra supplement required to increase the growth rate of the animals but did not include the costs of the initial implementation such as the cost of feeding ewes to improve conception rates or lamb survival.

MIDAS was selected as the appropriate modelling tool to quantify the on-farm benefits of improving each control point because it can efficiently examine the impacts of altering the range of production variables or management strategies on the farm. It models the whole flock and optimises animal and pasture management across the whole farm through the entire year. Optimising the management for each level of the control variables includes identifying the optimum stocking rate for the farm and also the allocation of the pasture resource and supplementary feed to the different classes of stock throughout the year. This ensures that each control point is compared with its optimum implementation.

The analysis included a number of control points and they were grouped into five areas. (1) Enterprise scale: pasture growth, pasture utilisation, distribution of pasture growth during the growing season and pasture species; (2) Flock structure: proportion of ewes mated to a terminal sire and proportion of wethers in the flock; (3) Reproduction efficiency: conception, lamb survival and mating ewe lambs; (4) Survival post-weaning: Mortality of weaners, ewes and wethers; and (5) Lamb finishing: Post weaning weight breeding value (PWWT) of the Terminal breed, PWWT of both the Maternal and Terminal breed and feeding of the lamb. The levels of production and the changes examined are outlined in Table 3.

Table 3. The control points and the levels examined in the MIDAS analysis.

	Unit of the control point	Standard model levels	Range examined
Enterprise scale			
Pasture growth	t/ha	7.4	7.4, 8.0, 8.7, 9.3
Pasture utilisation[1]	%	40	20, 30, 40
Distribution of growth			
Summer	kg/ha.d	3.6	3.6, 4.3
Autumn	kg/ha.d	16.7	16.7, 19.2
Winter	kg/ha.d	27.8	27.8, 33.2
Early spring	kg/ha.d	40.4	40.4, 48.1
Late spring	kg/ha.d	36.0	36.0, 42.9
Pasture system[2]		Moderate ryegrass	High performance ryegrass Moderate ryegrass Lucerne Triple pasture[3]
Flock structure			
Proportion of ewes mated to a terminal sire	%	45	0, 5, 10, 20, 30, 40, 45
Proportion of wethers in flock[4]	%	16	0, 16, 27, 36, 41
Reproduction efficiency			
M-M Conception (scanning)	%	127	127, 137, 147
M-TS Conception (scanning)	%	127	127, 137, 147

M-M Lamb survival	%	66	66, 71, 76
M-TS Lamb survival	%	70	70, 75, 80
Mating ewe lambs			
Proportion mated	%	0	0, 50, 100
Lambs weaned	%	-	35,50,65 at 39kg joining weight 35,45,65 at 42kg joining weight
Survival post-weaning			
Weaner mortality	%	5	3, 5, 7
Ewe mortality	%	4.7	2.7, 4.7, 6.7
Wether mortality	%	4	2, 4, 6
Lamb finishing			
PWWT of terminal breed	kg	5	5, 17
PWWT of the merino breed	kg	0	0, 12
Lamb feeding level	Weeks to turn-off	24	20, 24

1. Pasture utilisation = Pasture consumed (t/ha) / Pasture grown (t/ha)
2. Pasture systems described by Young et al. 2004
3. Triple pasture is Lucerne on the tops of hills, high performance ryegrass on the mid-slopes and Fescue on the valley floors.
4. Proportion of wethers = (number of wether hoggets + adult wethers) / (number of ewe hoggets + adult ewes + wether hoggets + adult wethers). Different proportions were achieved by altering the age at which wethers are sold.
5. The increase in PWWT was selected to reduce the time to turn off for the M-TS lamb by 1 month.

Estimation of potential on-farm improvement

The potential industry improvement in total emissions was calculated using the steps from the beef cattle herd management method. This involves multiplying the level of production of meat and wool in the national sheep flock (Table 4), the change in EIM+W per unit change in each control point from the MIDAS analysis described above and the potential for change from the current average industry level to a realistic industry level (Table 5).

Table 4. Weight of meat sold and weight of wool produced and the number of sheep (millions) in each class and flock types used for the analysis of industry-level impacts from varying control points to reduce emissions intensity. M-M is merino ewes mated to merino sires, M-TS is merino ewes mated to a terminal sire.

Segment	M-M	M-TS
Adult ewes (m ewes)	23.1	9.4
Ewe lambs (m lambs)	7.0	0
Weaners (m weaners)	9.7	1.2
Wethers (m wethers)	7.5	
Finished lambs sold (m lambs)		8.4
Meat sold (m kg liveweight)	730	
Wool produced (m kg greasy)	273	
Area of pasture grazed by sheep (m ha)	7.1	

Table 5. MIDAS values calculated for change in emissions intensity and the change in profit from an incremental increase in each control point associated with managing emissions.

	Unit of the control point	Change in emissions intensity per unit increase in the control point	Change in profit per unit increase in the control point	
		(kg CO_2-e/kg Meat + Wool)	Unit of profit	Value
Enterprise scale				
Pasture growth	t/ha	0	$/ha	83.61
Pasture utilisation	utilisation %	0	$/ha	9.22
Flock structure				
Proportion of ewes mated to a terminal sire	terminal %	-0.031	$/ewe	0.15
Proportion of wethers in flock	wether %	0.058	$/animal	-0.11
Reproduction efficiency				
M-M Conception (scanning)	scanning %	-0.024	$/ewe	0.17
M-TS Conception (scanning)	scanning %	-0.018	$/ewe	0.21
M-M Lamb survival	survival %	-0.068	$/ewe	0.56
M-TS Lamb survival	survival %	-0.050	$/ewe	0.58
Mating ewe lambs	weaning %	-0.023	$/ewe lamb	0.40
Survival post-weaning				
Weaner mortality	mortality %	0.121	$/weaner	-0.86
Ewe mortality	mortality %	0.301	$/ewe	-1.50
Wether mortality	mortality %	0.036	$/wether	-1.22
Lamb finishing				

PWWT of terminal breed	PWWT kg	-0.086	$/lamb	1.43
PWWT of the merino breed	PWWT kg	-0.008	$/lamb	-2.08
Lamb feeding level	Weeks to turn-off	-0.012	$/lamb	1.10

The potential change in industry profit was calculated by multiplying the number of production units in the national flock (number of ewes, weaners, wethers, sheep, area of pasture or tonnes of supplement), the change in profit per production unit per unit change in each control point from the MIDAS analysis and the potential for change from the current average industry level to a realistic industry level. Estimates of total sheep numbers, area of pasture and production of meat and wool were provided from MLA Sheep Industry projections in 2011 (K. Curtis, pers. comm.).

b) Phase 2 - ground truthing

MIDAS

There are a number of regional versions of MIDAS representing different agro-ecological zones with different climate, different land management units (LMUs) and different potential landuses. Each LMU has different production potential for each possible landuse. The model used in this analysis represented a livestock property in a 600 mm rainfall zone and included 3 LMUs. The annual legume Biserrula was included as an option on each LMU. Biserrula has been shown to have antimethanogenic properties but animals also show reduced weight gain. MIDAS is suited to evaluating this trade-off because the optimisation ensures that the Biserrula is managed to utilise the advantages while minimising the trade-off.

Analysis

The analysis quantified the impact on profitability from the low methane sheep and the anti-methanogenic pastures, and included:

1. Valuing the emissions saved. The price for carbon examined was $0, $15, $30 and $100 per tonne.
2. Capturing the energy that would have been lost as methane. There is no evidence that the energy that would have been lost is captured by the animal so the standard assumption was that the energy was lost, however, it is theoretically possible that the energy can be captured by the animal so this was examined in a sensitivity analysis.
3. Including the changes in animal and pasture production of the new pasture species. The analysis evaluated the benefit of growing Biserrula if enteric methane was not affected and only the impacts on pasture growth and digestibility, and animal production were included.

Data

The data used to calibrate the model and to decide the level of the sensitivity analysis was:

1. Growth rate of the different species. The growth rate measurements showed no significant difference in the growth rate of the Biserrula compared with the other treatments. In the analysis a sensitivity analysis was done examining if Biserrula had 100% or 90% of the growth rate of sub-clover and ryegrass.

2. Feed quality of pasture. There were differences in diet quality in a trial with irrigation and this showed that the digestibility of ryegrass was lower in summer/autumn, but not different between Biserrula and Antas sub-clover (FTRG project – Efficient livestock with low emissions (ELLE)). In this current project, the difference in digestibility was not obvious and in the analysis it was assumed that the digestibility of all the species was the same.

3. Animal performance when grazing the different species. Animal measurements showed that the liveweight gain when grazing Biserrula was 20% lower than when grazing other pastures, however, it was inconclusive whether this occurred on just green pasture or on green and dry pasture. In the analysis it was examined as a sensitivity analysis whether the reduction was only on green feed or on both green and dry feed. It was assumed that this reduction in animal production was due to lower intake of Biserrula rather than a reduction in the efficiency of use of energy.

4. Reduction in methane when grazing Biserrula. The results of the pen trial that examined diets with different proportions of Biserrula showed a dose response in methane emissions, so in the analysis it was assumed that the reduction in methane was proportional to the proportion of the energy in the diet supplied by Biserrula. The reduction in emissions from grazing Biserrula varied between experiments. The pen trial showed

    a. an average reduction of 27.5% when fed at maintenance, however, this had a wide confidence interval.

    b. A reduction of 16% when fed at twice maintenance.

However, the paddock trial grazing Biserrula *ad lib* showed no reduction in emissions. In the analysis it was assumed that the impact on emissions of grazing Biserrula was dependent on the level of energy intake. At maintenance it was assumed there was a 27.5% reduction (sensitivity 10% & 50%), reducing to either a 0% or 16% reduction at twice maintenance.

5. Low methane genotype. It was assumed that the low methane genotype had a 10% lower methane yield than the standard genotype and that this was achieved without a trade-off of lower production in other traits. This is an optimistic assumption because other work has shown that methane yield has low correlation with the other production traits and therefore

selecting animals for reduced methane yield will reduce the selection pressure on the other production traits without necessarily providing a positive correlated response.

3. Results

Activity 1: Methane and animal production from pastures varying in methanogenic potential (animal house experiment 1)

In vitro assessment of nutritive value

The nutritive values of the pastures varied significantly between species (Table 1). Biserrula contained the highest levels of digestible energy and bladder clover the lowest ($P<0.05$). Biserrula was lower than other species in neutral detergent fibre and ash and equal highest with serradella in crude protein, organic matter and gross energy ($P<0.05$). Biserrula was the most digestible pasture while bladder clover was the least digestible pasture ($P<0.05$). Subclover contained the highest levels of ash and the lowest levels of organic matter ($P<0.05$). Lignin was highest in serradella ($P<0.05$).

Table 1. Mean chemical composition of pastures from daily samples bulked weekly (n=5 per forage). Mean grams (g) per kilogram (kg) dry matter (DM) of crude protein (CP), organic matter (OM), dry matter digestibility (DMD), dry organic matter digestibility (DOMD), neutral detergent fibre (aNDF), acid detergent fibre (ADF), acid detergent lignin (ADL), fat, and cold water soluble carbohydrates (WSC); and mega joules (MJ) of gross energy (GE) and digestible energy (DE) of fresh ryegrass (RG) bladder clover (BC), subterranean Clover (SC), serradella (Ser), or Biserrula (Bis).

Composition (g/kg DM)	RG	BC	SC	Ser	Bis	F pr
CP	136^{c}	190^{b}	181^{b}	227^{a}	232^{a}	<.001
OM	911^{a}	893^{b}	870^{c}	910^{a}	908^{a}	<.001
DMD	807^{a}	653^{d}	698^{c}	690^{c}	769^{b}	<.001
DOMD	752^{a}	621^{d}	659^{c}	653^{c}	720^{b}	<.001
aNDF	500^{a}	468^{b}	388^{c}	353^{d}	298^{e}	<.001
ADF	251^{b}	312^{a}	250^{b}	253^{b}	213^{c}	<.001
ADL	30^{c}	67^{b}	70^{b}	97^{a}	57^{b}	<.001
Ash	74^{b}	78^{b}	104^{a}	69^{b}	59^{c}	<.001
Fat	23^{a}	16^{b}	23^{a}	23^{a}	22^{a}	<.01
WSC	204^{a}	68^{b}	88^{b}	58^{b}	81^{b}	<.001
Energy (MJ/kg DM)						
GE	17.5^{b}	17.0^{c}	17.2^{c}	18.6^{a}	18.7^{a}	<.001
DE	14.1^{a}	11.1^{d}	12.0^{c}	12.8^{b}	14.2^{a}	<.001
ME	12.3	9.6	10.4	10.2	11.6	<.001

*Means with different superscripts within a row differ ($P<0.05$).

In vivo *estimates of methane production*

The difference in methane yield from sheep fed fresh pasture was greatest when expressed on a digestible energy basis (CH_4 g/MJ DE intake). Sheep fed Biserrula produced significantly lower methane yields compared to other legumes per unit intake of digestible energy (Figure 1), and per kilogram of dry matter intake. The methane yields from Biserrula were significantly lower than the other legume pastures on the basis of dry matter intake on the day that methane was measured and when intake was averaged over the day that methane was measured and the intake on the day prior to measurement (Table 2).

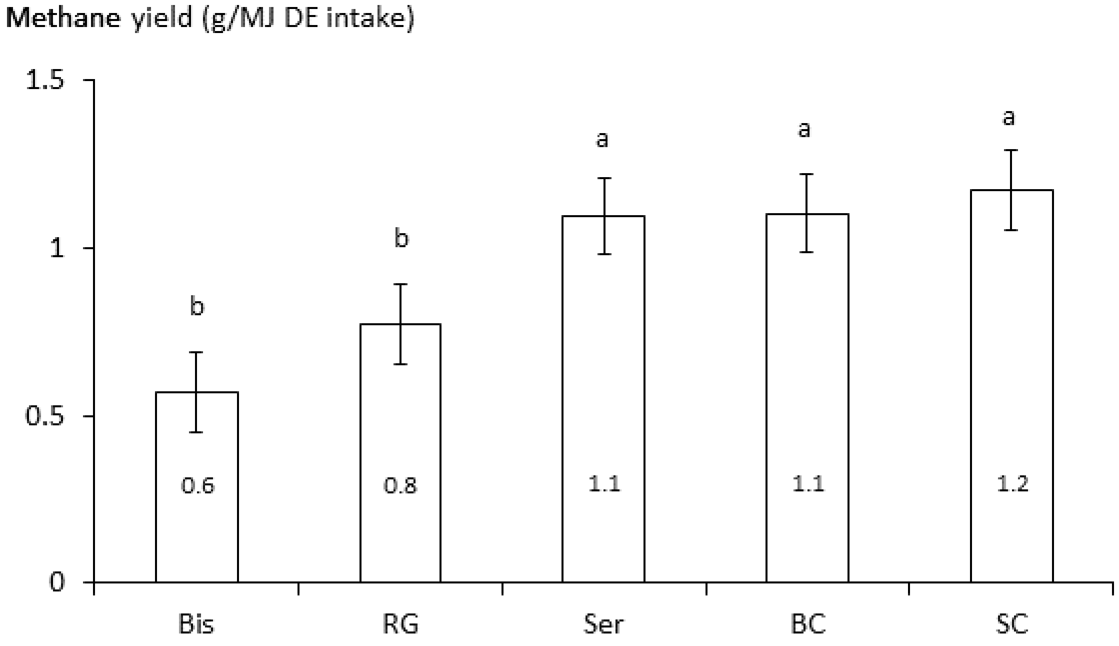


Figure 1. Predicted mean in grams (g) for 23h methane yield relative to intake of mega joules (MJ) of digestible energy (DE) from sheep fed fresh Biserrula (Bis), ryegrass (RG), serradella (Ser), bladder clover (BC), or subterranean clover (SC), for 4 weeks at 1.2 times maintenance (n=10-12 sheep/pasture). Predicted means with different superscripts above columns differ (F pr <0.01).

The effect of treatment diet on methane yield was significant and the effect was largely driven by dry matter intake and the nutritive components of the feed. There were strong positive correlations between methane yield and the more indigestible nutritive components of the pastures (ADF, 0.43 and ADL, 0.38) (Figure 2).

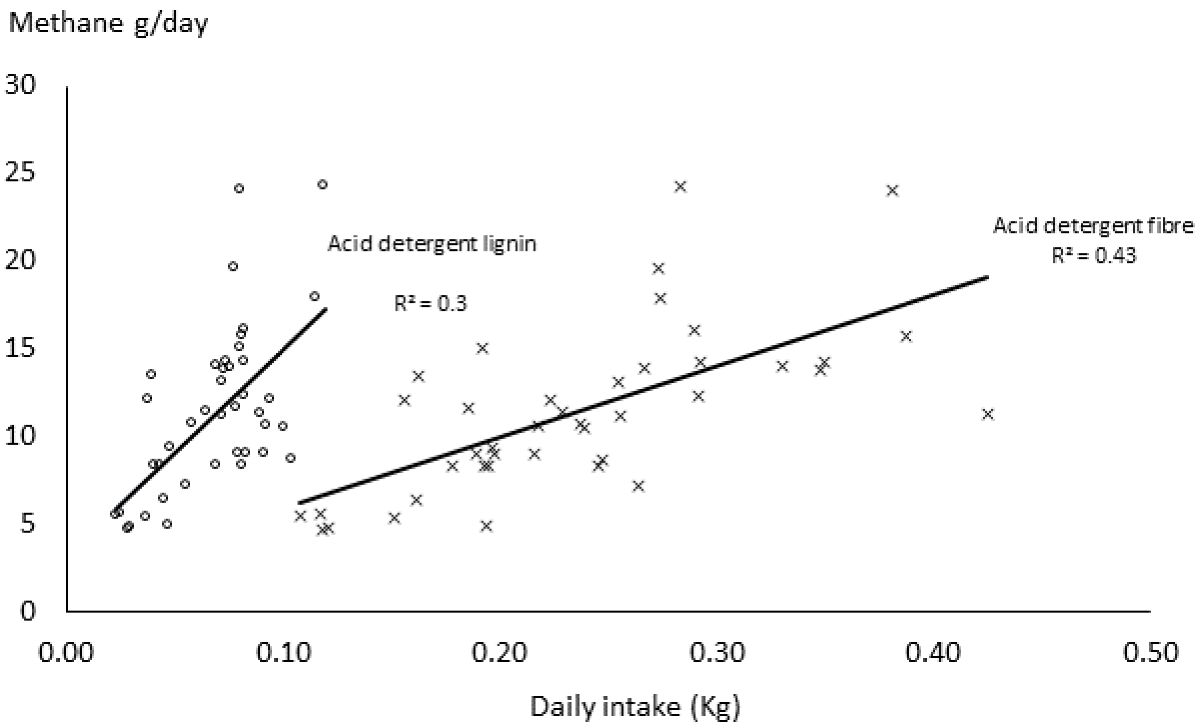


Figure 2. The pasture components most strongly correlated with daily methane production

In vitro

There was a significant effect of pasture type on methane yield in the IVFT (P<0.001). Biserrula produced the lower methane yields (P<0.001) and bladder clover produced higher (P<0.05) methane yields compared with other treatments Figure 3.

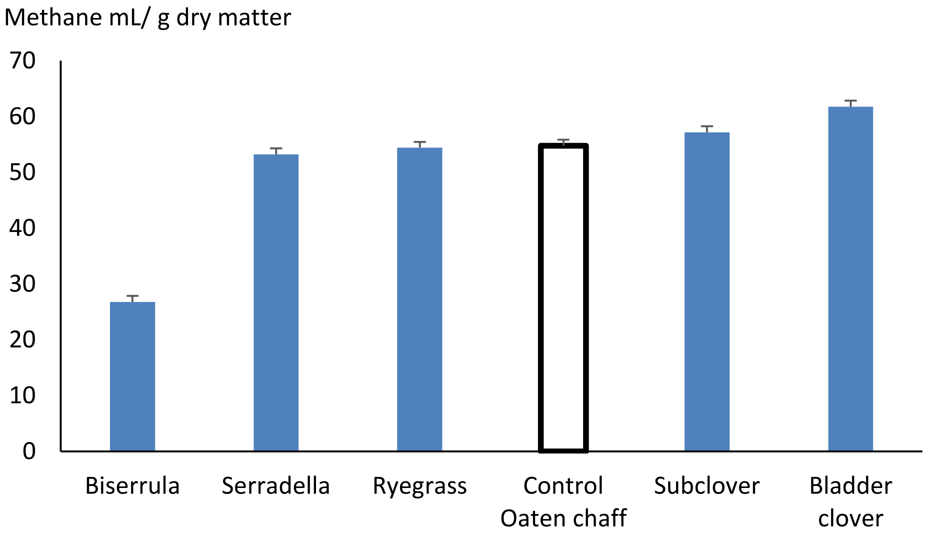


Figure 3. The effects of pasture species on methane yields using an *in vitro* fermentation technique.

Activity 2: Methane and animal production from manipulating diet composition (animal house experiment 2)

In vivo

There was no significant effect of sampling time on the nutritive value of ryegrass or Biserrula and therefore the mean nutritive values are presented in Table 2. On average, Biserrula had a higher metabolisable energy (ME) and crude protein (CP) content, and lower neutral detergent fibre (NDF), acid detergent fibre (ADF) and hemicellulose content than ryegrass (P<0.001). There was no significant difference in the average ash content between ryegrass and Biserrula samples.

Table 2. Mean nutritive values of ryegrass and Biserrula chaff fed to sheep in varying proportions for 38 days.

Nutritive value	Ryegrass	Biserrula	P value
Neutral detergent fibre (%)	64±0.2	40±0.4	<0.001
Acid detergent fibre (%)	35±0.1	27±1.9	<0.001
Hemicellulose (%)	29±0.9	13±1.4	<0.001
Crude protein (%)	7.5±0.19	14.5±0.30	<0.001
Ash (%)	8.8±0.58	10.8±4.10	n.s.
Metabolisable energy (MJ/kg dry matter)	7.2±0.06	9.4±0.05	<0.001

n.s, not significant.

Diets were balanced for energy intake rather than dry matter intake, however, refusals of the 100% ryegrass treatment resulted in lower intakes and lower growth rates than expected (Table 3). There was a dose response to Biserrula in the total volatile fatty acids and acetate:propionate ratio. There was also a dose response to Biserrula in the reduction of total methane and methane produced per unit of metabolisable and gross energy.

Table 3. Mean methane production and methane yield for sheep fed 100% ryegrass (RG 100%), 67% ryegrass 33% Biserrula (RG 67% B 33%), 33% ryegrass 67% Biserrula (RG 33% B 67%) and 100% Biserrula (B 100%). Dry matter intake (DMI), metabolisable energy intake (MEI), gross energy intake (GEI).

Treatment Group	RG 100%	RG 67% B 33%	RG 33% B 67%	B 100%	P value
Dry matter intake (as fed g/day)	986 ^{ab}	1025 ^{a}	934 ^{b}	833 ^{c}	<0.001
Average live weight gain (g/day)	15 ^{a}	57 ^{b}	43 ^{b}	44 ^{b}	<0.05
Total volatile fatty acids (mmol/L)	52 ^{a}	67 ^{b}	78 ^{c}	76^{c}	<0.001
Acetate : Propionate	4.2 ^{a}	3.8 ^{ab}	3.4 ^{bc}	2.9 ^{c}	<0.001
Methane production (g/day)	10.5 ^{a}	9.9 ^{ab}	8.7 ^{ab}	8.4 ^{b}	0.05
Methane yield (g/day)					
/kg DMI	12.3 ^{a}	10.4 ^{a}	10.0 ^{a}	10.5 ^{a}	0.20
/MJ MEI	1.8 ^{a}	1.4 ^{b}	1.1 ^{bc}	1.0 ^{c}	0.001
/MJ GEI	0.67 ^{a}	0.67 ^{a}	0.51 ^{ab}	0.49 ^{b}	0.05

In vitro

There was a dose response to methane yield based on the level of Biserrula inclusion in the substrate used in the IVFT indicating an inhibition of methanogenesis (($P<0.05$); Table 4). Cumulative gas production was significantly lower at the 100% and 67% levels of Biserrula inclusion, which can be an indirect indicator of fermentation being inhibited, however total volatile fatty acid production was not inhibited ($P<0.05$) at the 100% level of inclusion. For Biserrula this indicates that the lower gas production was proportional to the methane reduction rather than lower fermentation activity. There was a dose response in the acetate to propionate ratio and ammonia production based on the level of Biserrula inclusion in the diet ($P<0.05$). The inclusion of Biserrula increased the proportion of propionate produced,, which is favourable for glycolysis and animal production and reflective of decreased methanogenesis. The higher levels of ammonia are reflective of higher levels of crude protein in the diet and indicate an excess of protein at the 100% and 67% levels of Biserrula inclusion.

Table 4. The effects of pasture species on methane yields using an *in vitro* fermentation technique (IVFT).

	CH_4 mL g^{-1} DM	Gas pressure kPa	VFA mmol L^{-1}	Acetate: Propionate	NH_3 mg L^{-1}
Biserrulla	18.5^a	318^a	84^a	2.26^a	202^a
67Bis:33RG	28.1^b	324^a	72^b	2.89^b	167^b
33Bis:67RG	37.1^c	357^b	82^a	3.36^c	95^c
Ryegrass	35.1^c	355^b	79^a	3.32^c	76^c
F pr	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Activity 3: Plot scale grazing trials 2014 and 2015

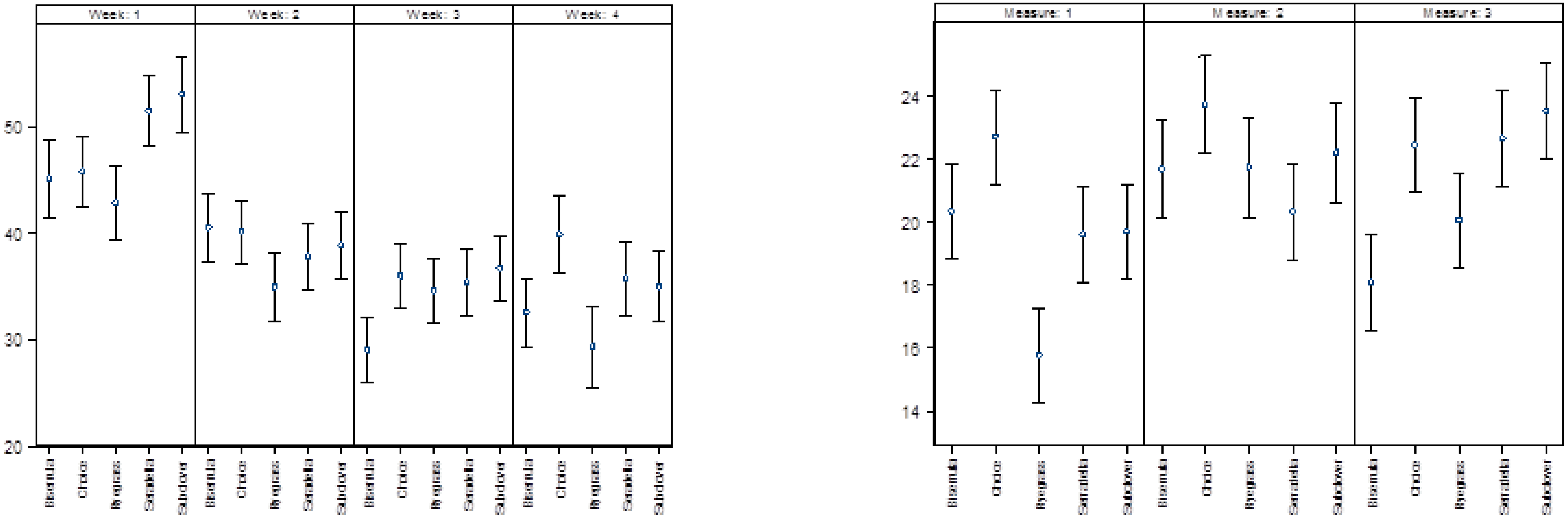
a) Western Australia

Plot-scale grazing experiments

Feed on offer was maintained at levels that would not restrict intake (>1200 kg DM/ha) for all pastures over two spring grazing seasons. Biserrula had the lowest ($P<0.05$) average fibre component (ADF and NDF) in both seasons and annual ryegrass had the lowest CP and highest ME composition over both seasons (Table 5). The 2014 pastures tended to contain lower levels of fibre and higher CP and ME than in 2015. The “Choice”, subclover and serradella pastures produced the highest growth rates in the sheep in 2014 and 2015. In 2014 there was an effect of pasture on average total daily methane emissions but the effect was not evident in 2015. Methane intensity in this study was defined as grams of methane emitted per Kg of average daily live weight gain. There was no effect of pasture type on average methane intensity. Figures 4 and 5 show the total daily methane emissions and methane intensities at each measurement over the two growing seasons. No clear effect of pasture type on methane emissions is obvious from these measurements.

Table 5. Average nutritive values of pastures and the effect on average daily weight gain (ADG g/day) and methane intensity (iCH_4 g/Kg ADG).

	Sward purity %		ADF %		NDF %		CP %		ME MJ/kg DM		ADG g/day		CH_4 g/day		iCH_4 g/Kg ADG	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Choice	92	82	23.4	25.4	43	48	18.2	16.0	9.9	9.4	211	260	29	23	228	93
Sub	95	85	23.5	26.2	41	47	20.1	18.7	9.7	9.2	190	267	30	22	226	85
ARG	96	98	21.4	23.8	43	49	11.4	9.6	10.5	9.9	154	205	26	19	172	89
Serr	90	42	23.6	24.1	38	40	18.7	18.7	9.2	9.2	196	272	29	21	224	80
Bis	93	79	19.6	20.9	33	36	19.1	18.4	10.0	9.5	164	210	26	20	197	95
Fpr	-	-	<0.05	<0.05	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	.20	<0.05	0.40	<0.05	0.35	0.07



2014

2015

Figure 4. Predicted means and standard errors of absolute methane emissions (g CH_4/ day) from sheep over two spring grazing seasons. Methane was measured every two to three weeks from individual sheep using portable accumulation chambers and a flame ionisation device.

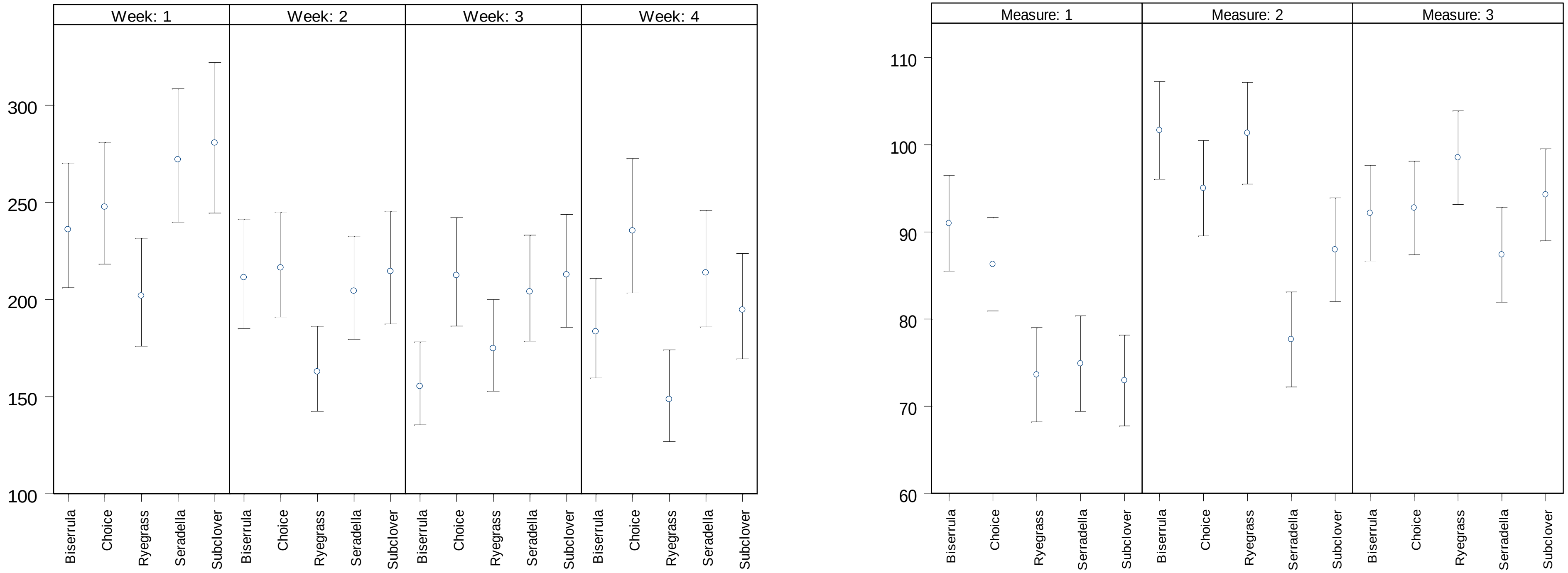


Figure 5. Predicted means with standard error for the interaction of methane measure and pasture type on methane intensity (g CH_4/ Kg live weight gain) over two spring grazing seasons.

In vitro **assessment of methane potential**

There was no difference (P=0.52) in the average methane yield between sampling weeks and the average methane yield across all treatments was 28 mL/ g DM +/- 1.9). There was an effect of pasture type on mean methane yield and within each week of pasture sampling (P<0.001) (Figure 6). Biserrula produced the lowest mean yield and the lowest yield at each sampling point (P<0.001). Biserulla produced the lowest (P<0.001) mean cumulative gas with 307, 354, 362, 369, and 391 mL/g DM for Biserrula, subclover, serradella 70sub:30Rye, and ryegrass respectively.

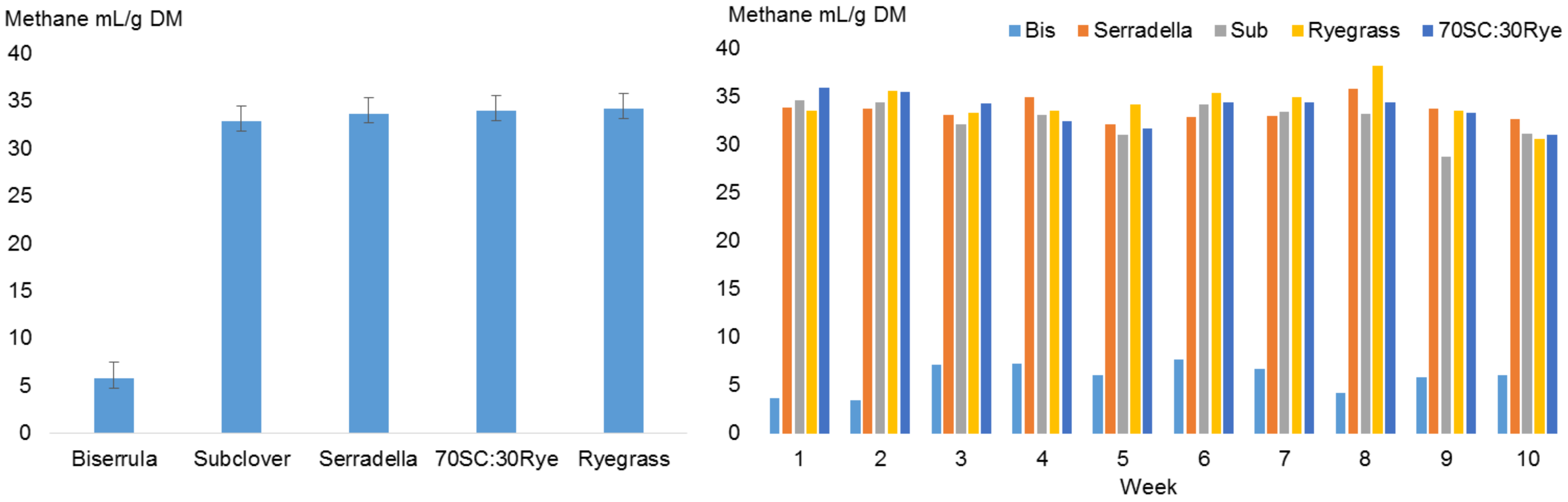


Figure 6. The mean effects of pasture species on methane yields using IVFT, mean effects (left) and over time (right) using plant samples taken weekly for ten weeks from the plot-scale grazing experiment in 2014.

a) Victoria

Feed on offer

FOO decreased over the grazing period in most forage types (Figure 7). FOO was typically lower in the arrowleaf and lucerne pastures than in choice or perennial ryegrass (choice is displayed here as a mean of the clover and grass pasture available). Anecdotal evidence suggested that sheep offered the choice system preferentially grazed the arrowleaf clover pasture before the perennial ryegrass pasture, which may have affected subsequent methane emissions. Similarly, sheep offered lucerne pastures grazed the leaf material in preference to stem. Further investigation of the interaction between FOO and nutritive characteristics is required.

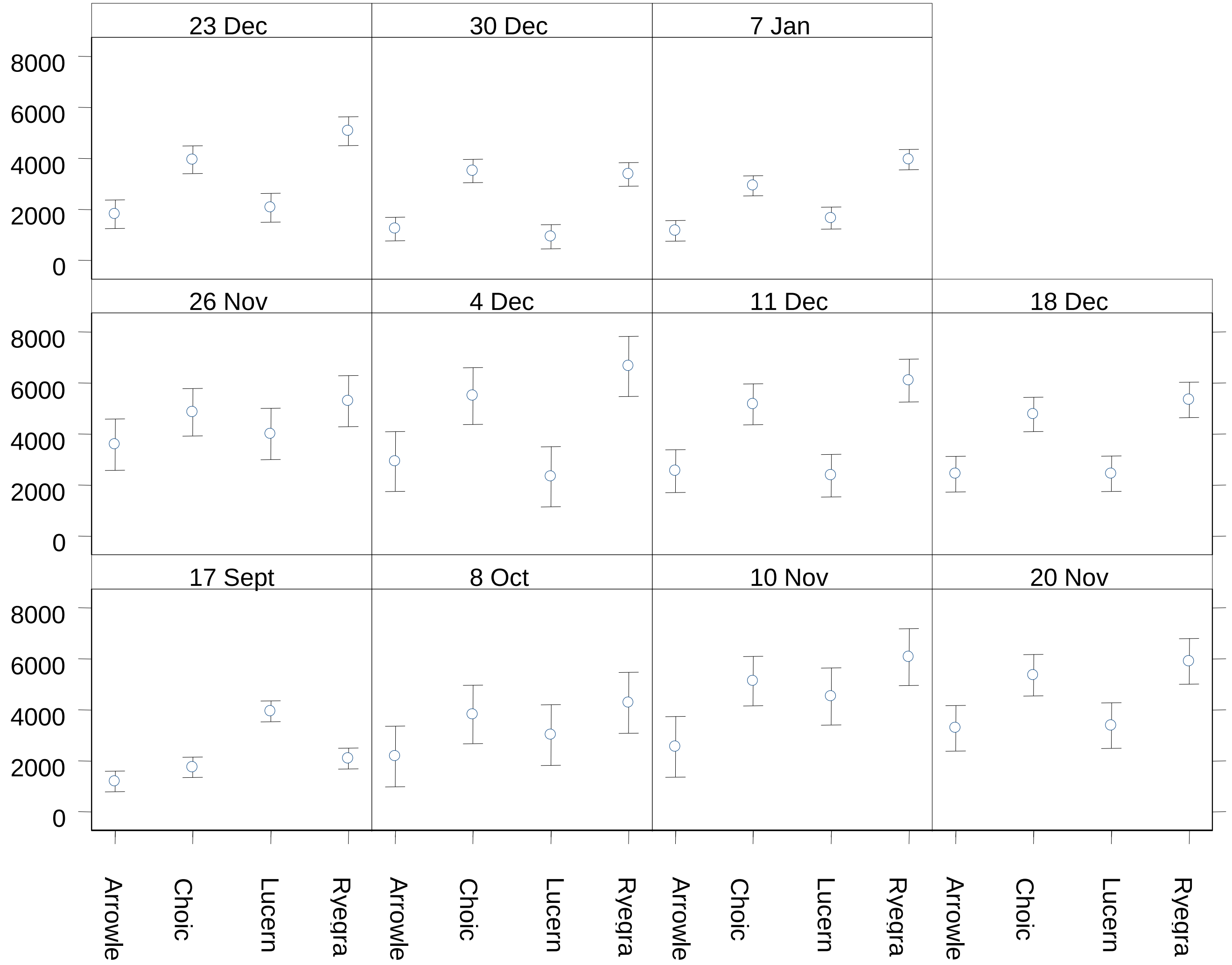


Figure 7. Change in FOO (kg DM/ha) for Arrowleaf (Arrowle), Choice (Choic), Lucerne (Lucern) and Ryegrass (Ryegra) pasture treatments over the grazing period (pre-allocation September/ October bottom left, end of grazing top right). Comparisons are only valid within each time point.

Nutritive characteristics

A summary of nutritive characteristics is presented in Table 6. There is evidence of a change in nutritive characteristics over the grazing period from 11 November, 2015 to 7 January, 2016 in all forage treatments.

Table 6. Key nutritive characteristics (mean) of all forage treatments in Experiment 2 – dry matter digestibility (DMD), crude protein (CP), acid- detergent fibre (ADF) neutral-detergent fibre (NDF) content and estimated metabolisable energy (ME) determined by near-infrared (NIR) spectroscopy. Treatment means shown.

	Treatment				P Value			
	Arrowleaf	Choice	Lucerne	P. Rye	Treatment	Date	Interaction	s.e.d
DMD %	53.2	54.9	39.6	55.2	<0.001	<0.001	<0.05	2.5*
Estimated ME MJ/kg DM	6.60	7.50	4.63	7.59	<0.001	<0.01	<0.05	0.53*
CP %	5.80	6.28	6.22	5.30	NS	<0.01	<0.05	1.04*
ADF %	35.7	34.4	47.8	35.8	<0.001	NS	NS	1.7^
NDF %	50.2	61.2	67.5	64.3	<0.001	NS	NS	2.3^

^treatment s.e.d, *s.e.d for interaction

Treatment	Forage Type	CP (%)	NDF (%)	ME (MJ/kg DM)
Arrowleaf	Arrowleaf	5.8 ± 3.2	50.2 ± 9.4	6.6 ± 1.3
Choice	Arrowleaf	7.6 ± 1.7	59.6 ± 8.4	7.3 ± 1.1
	Ryegrass	5.1 ± 1.4	62.6 ± 6.8	7.6 ± 1.1
Lucerne	Lucerne	6.2 ± 1.1	67.5 ± 3.7	4.6 ± 0.7
Ryegrass	Ryegrass	5.3 ± 1.8	64.3 ± 6.6	7.6 ± 1.2

Animal Performance

All animals gained weight over the grazing period for Experiment 2 (Effect of date, *P*<0.001). However, there was no significant effect of forage type on live weight gain (*P*>0.05). We also observed a slow decline in all animals' liveweight over the grazing period from the 15 December to the 5 January (Table 7). This correlated with change in FOO or nutritive characteristics in most forage types.

Table 7. Effect of forage and sampling date on live weight (kg) of sheep grazing forages.

					P Value		
Date	Arrowleaf (kg)	Choice (kg)	Lucerne (kg)	Ryegrass (kg)	Date	Forage	Interaction
11 Nov	67.2	67.7	67.9	67.2	<0.001	0.082	0.673
03 Dec	73.1	74.2	73.7	71.7			
15 Dec	75.0	74.6	74.5	72.3			
21 Dec	73.9	72.3	73.7	70.5			
05 Jan	72.9	71.7	73.1	70.0			

Methane Emissions

Forage type did not have a significant effect on methane emissions (P>0.05). However, there was a significant interaction (P<0.001) between forage type and sampling date (Table 8). Methane emissions were consistent in the arrowleaf and choice systems over time but dropped substantially at the final measurement period on both lucerne and perennial ryegrass pasture types. Anecdotally, this appears to coincide with the season drying off and the perennial ryegrass pasture becoming rank and 'poorer' quality and the lucerne pasture becoming more stalky (despite FOO indicating reasonable availability) - it is likely that the sheep would have preferentially grazed the lucerne leaf material first.

During this period, there was a non-significant decrease in live weight on all forage types. These observations suggest that feed intake may have been lower during this period.

Table 8. Mean methane emissions (g/day) for sheep grazing different forages at three test periods over summer in south west Victoria.

					P Value		
Period	Arrowleaf (g CH_4/day)	Choice (g CH_4/day)	Lucerne (g CH_4/day)	Ryegrass (g CH_4/day)	Period	Forage	Interaction
1	27.9	31.0	27.0	34.0	0.054	0.301	<0.001
2	27.3	31.6	27.3	33.8			
3	26.5	30.9	22.8	23.9			

Comparison of Victoria and WA grazing trials in 2015

It is difficult to compare the experiments in Victoria and WA because the pasture species tested were different, other than the rygrass. The pasture species tested were different out of necessity, because not all species were suited in both environments so we needed to test what might make a difference in each location. However, the range in qualities of the pastures and the effects on animal growth and methane emissions at the two sites is shown in Table 9. The WA pastures tended to provide higher available energy to the sheep and animal growth rates were higher than at the Victorian site, but absolute methane emissions were similar or lower at the WA site. Subsequently, the methane intensities tended to be lower at the WA site.

Table 9. The range of effects of pastures on the efficiency of production in 2015 from plot-scale grazing sites at Victoria and Western Australia.

Site	Range of average feed quality ME	Range of average methane g/day	Range of average live weight gain g/day	Range of methane intensity CH_4 g/kg live weight gain
Hamilton Vic	4.6 to 7.6	24 to 34	52 to 105	262 to 589
Ridgefield WA	9.2 to 9.5	19 to 23	210 to 272	80 to 95

Activity 4: Wholefarm Systems Modelling

Pre-experimental analysis – critical control points

Standard farm plan

The level of farm profit and a summary of the farm plan for the standard flock management and genotype is shown in Table 6.

The standard farm profit was $230,000 or $230/ha and this was generated from 7,086 sheep carried through the winter and 68% of these were ewes. All ewes were retained in the flock until they were 77 months of age and a proportion of each age group and all of the oldest age group were mated to a terminal sire. The wethers were sold off shears at 17 months of age. The level of supplementary feeding was 177 tonnes or 25 kg/hd. The total emissions from the flock were 1,780 tonnes CO_2-e or 180 kg CO_2-e/DSE and EIM+W was 16.2 kg CO_2-e per kg liveweight plus greasy wool.

Table 6. The profit and production associated with the optimal farm plan

Parameter	Unit	Value
Farm profit	$/ha	230
Flock size		
Adult ewes (1.5, 2.5, 3.5, 4.5, 5.5 yo)	head	4830
Young ewes (retained at 0.5 yo)	head	1128
Wethers (retained at 0.5 yo and older)	head	1128
First cross lamb	head	1912
Flock structure (adult ewe head/total head in winter)	%	68
Sale age of animals		
Surplus young ewes	months	none sold
Cull adult ewes – merino-merino	months	65[1]
– merino-terminal	months	77
Wethers	months	17
Supplementary feeding	T	177
Emissions		
Total	t CO_2-e	1780
Emissions Intensity – meat	kg CO_2-e/kg meat	22.0
Emissions Intensity – wool	kg CO_2-e/kg wool	61.6
Emissions Intensity – meat + wool	kg CO_2-e/kg meat + wool	16.2

[1] Ewes older than 65 months are mated to a terminal sire

Scale

Increasing the scale of the sheep enterprise increased both farm profitability and total emissions by up to 400% (Fig.) but had little effect on emissions intensity, which varied less than 5% (Fig.). The change in farm profit relative to total emissions was approximately $203/t of extra CO_2-e. The relationship between total emissions and farm profitability was the same whether the scale was altered by changing pasture species, total pasture growth, the distribution of the pasture growth during the season or the proportion of the pasture growth that was utilised. Based on the options examined for changing enterprise scale, the total emissions from the farm was linearly related to total metabolisable energy intake (MEI) (Fig.). An increase of 1000 MJ in MEI was associated with an increase of 53 kilograms of CO_2-e. For the different management and production options examined in the analysis the level of total emissions were within the range +/-0.5% of this fitted regression equation.

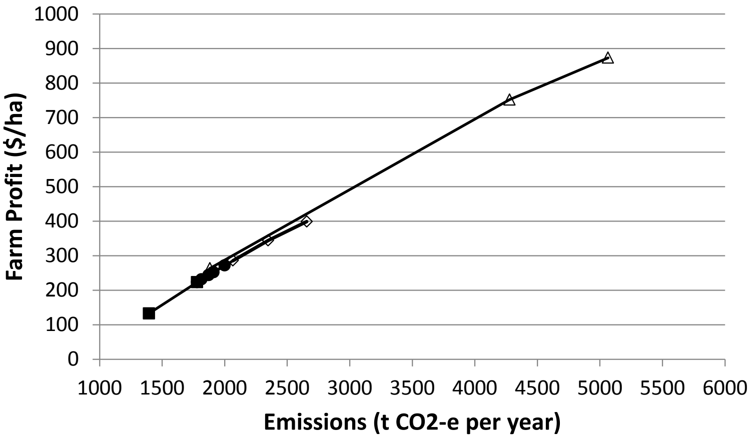


Fig. 1 Relationship between total emissions and farm profitability for the levels of the ‘scale’ control points (Δ pasture species, ◇ pasture growth rate, ● distribution of pasture growth during season, ■ utilization of pasture).

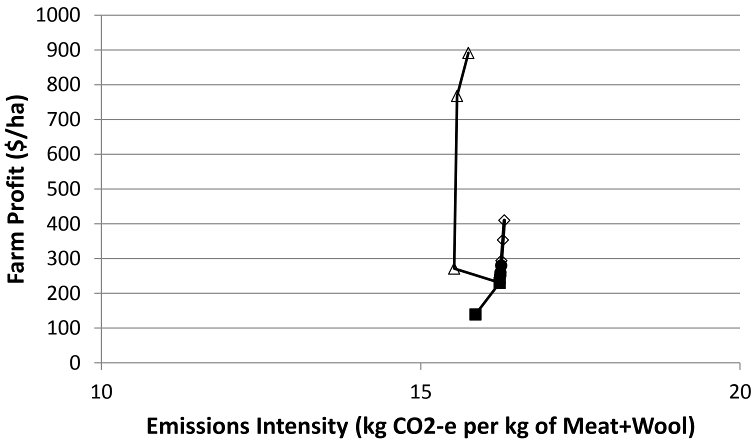


Fig. 2. Relationship between emissions intensity per kilogram of meat and wool combined and farm profitability for the levels of the 'scale' control points (Δ pasture species, ◇ pasture growth rate, ● distribution of pasture growth during season, ■ utilization of pasture).

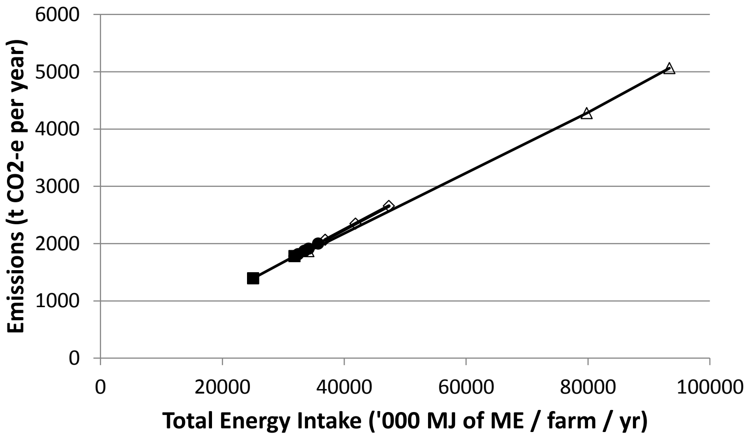


Fig. 3. Increasing metabolisable energy intake increases total emissions and the relationship is independent of the method used within the 'scale' control points (Δ pasture species, ◇ pasture growth rate, ● distribution of pasture growth during season, ■ utilization of pasture).

Flock management options

When the flock structure, reproduction efficiency, survival post-weaning and lamb finishing control points were varied there was no relationship between whole farm profit and total emissions. Whole farm profit varied in the range $170 to $240/ha but for most of the control points total emissions did not change (Fig.). However, the variation in profit was correlated favourably with EIM+W (Fig.). Adopting these management practices reduced emissions intensity by between 0.26 and 0.61 kg CO_2-e per kg liveweight plus greasy wool for each $10/ha increase in farm profitability.

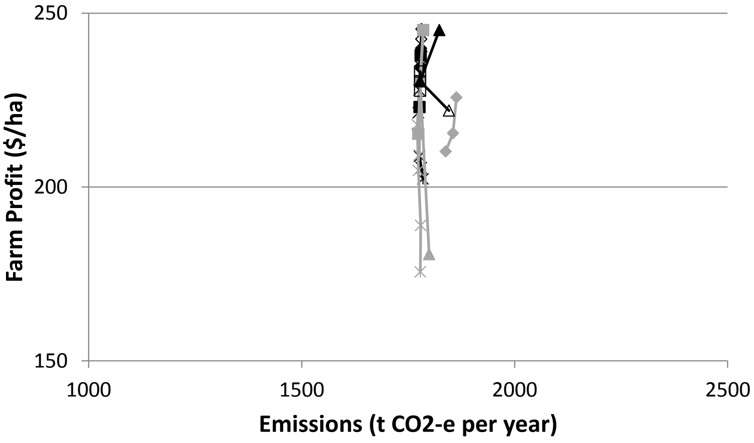


Fig. 4. Relationship between total emissions and farm profitability for the levels of the ‘flock’ control points (∗Proportion of ewes mated to a terminal sire, ∗ proportion of wethers in the flock), the reproduction control points (♦ conception, ◊ lamb survival, merino-merino solid line, merino-terminal dashed line, ♦ weaning percentage achieved from ewe lambs), the survival control points (■ weaners, ■ ewes, □ wethers) and the lamb finishing control points (▲PWWT of terminal breed,▲ PWWT of the merino, ∆ lamb feeding rate).

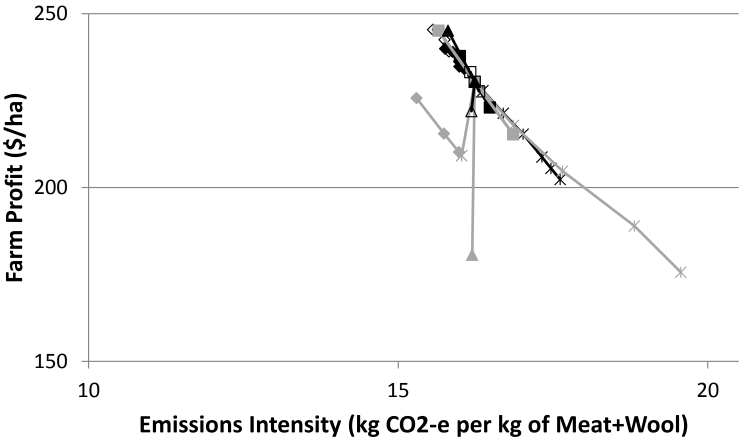


Fig. 5. Relationship between emissions intensity per kilogram of meat and wool combined and farm profitability for the levels of the ‘flock’ control points (∗Proportion of ewes mated to a terminal sire, ∗ proportion of wethers in the flock), the reproduction control points (♦ conception, ◊ lamb survival, merino-merino solid line, merino-terminal dashed line, ♦ weaning percentage achieved from ewe lambs), the survival control points (■ weaners, ■ ewes, □ wethers) and the lamb finishing control points (▲PWWT of terminal breed,▲ PWWT of the merino, ∆ lamb feeding rate).

Flock structure

The improvement in EIM+W and profit were both linearly related to the proportion of ewes mated to a terminal sire (Fig.). The slope of these lines provides the MIDAS coefficients in **Table** for change in emissions intensity or profit per unit increase in the control point. The linearity indicates that the coefficient is valid over the entire possible range of the proportion of ewes mated to a terminal sire.

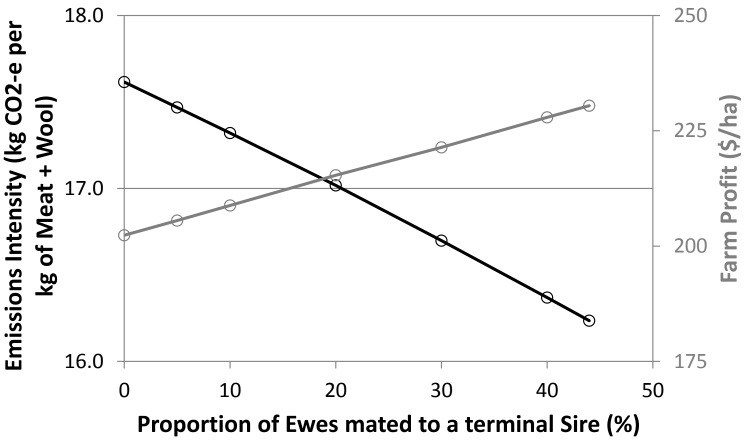


Fig. 6. Increasing the proportion of ewes mated to a terminal sire reduces emissions intensity per kilogram of meat + wool (black line) and increases profitability (grey line).

The variation in EIM+W and profit associated with the proportion of wethers in the flock was not linear (Fig.). The reductions in EIM+W when the proportion of wethers was reduced from 45% down to 25% was 0.13 per % and was associated with a $40/ha increase in profit on the typical farm. However, the reduction in EIM+W was only 0.06 per % when the proportion of wethers was reduced from 25% to 15%. The national flock has an average of 15% wethers and the magnitude of the savings in emissions generated from a further reduction in the proportion of wethers will depend on the starting point of the flocks that adjust. For **Table** the slope of the line from 25% to 15% was used to calculate the national potential.

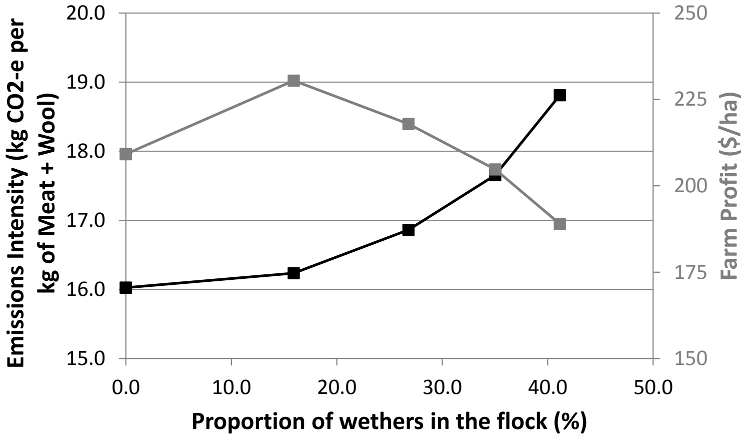


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Fig. 7. Increasing the proportion of wethers in the flock increases emissions intensity per kilogram of meat + wool (black line) and reduces profitability (grey line).

Reproduction efficiency

The improvement in EIM+ W was linearly associated with increasing scanning percentage for both ewes mated to merinos and ewes mated to terminal sires (Fig.) and the slope of the regression equations was -0.024 and -0.018 kg CO_2-e/kg Meat + Wool per 1% increase in scanning. The improvement in profit was linearly associated with increase in scanning percentage and the slope was \$0.17 and \$0.21/ewe per 1% increase in scanning for merino-merino (M-M) and merino-terminal (M-TS) respectively. The higher value for the M-TS mating is related to the higher sale value of the M-TS lamb and the higher survival levels of the M-TS lambs, which means more of the extra lambs scanned are converted into lambs alive at weaning.

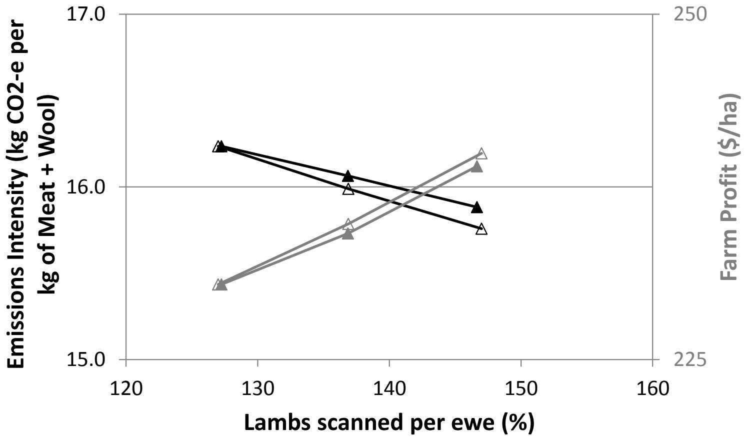

Fig. 8. Increasing conception rate for a merino-merino mating (open) and merino-terminal mating (solid) reduces emissions intensity per kilogram of meat and wool (black lines) and increases profitability (grey lines).

The improvement in EIM+W and profit are both linearly related with increasing lamb survival levels for both ewes mated to merinos and ewes to terminal sires (Fig.). The slopes for EIM+W are -0.068 and -0.050 kg CO_2-e/kg Meat + Wool per 1% increase in survival and for profit are \$0.56 and \$0.58/ewe per 1% increase in survival, respectively.

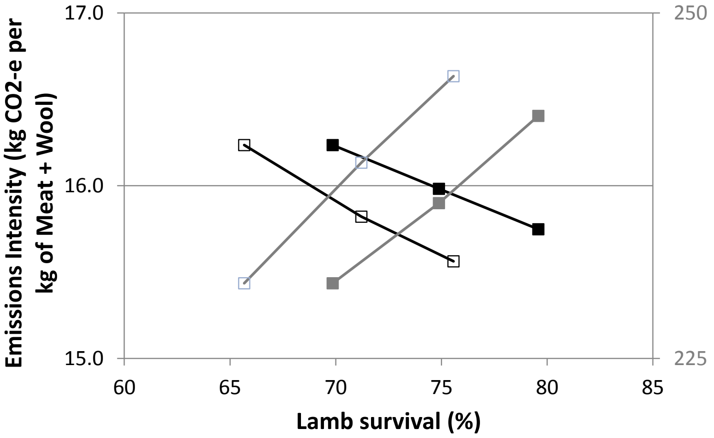

Fig. 9. Increasing the survival rate of merino-merino lambs (open) and merino-terminal lambs (solid) reduces emissions intensity per kilogram of meat and wool (black lines) and increases profit (grey lines).

The improvement in EIM+W with increasing weaning percentage was linear and it is the same relationship regardless of whether the improvement in weaning was achieved from increasing conception or increasing lamb survival or from the M-M mating or M-TS mating (Fig.). The improvement in profitability depended on how the improvement is achieved. The consistent relationship for EIM+W indicates that farmers and advisers wishing to improve emissions can focus on increasing weaning percentage without being concerned about how it is achieved.

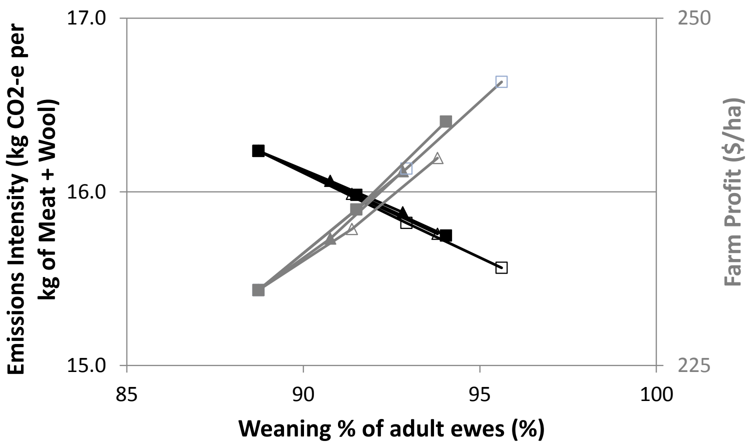

Fig. 10. Increasing weaning rate for merino-merino matings (open) and merino-terminal matings (solid) reduces emissions intensity per kilogram of meat and wool (black) and increases profitability (grey). The relationship between weaning rate and emissions intensity per kilogram of meat plus wool is independent of whether it is achieved by increasing conception (triangles) or increasing survival (squares).

Mating ewe lambs increased total emissions (Fig.) due to the extra feeding required to get the lambs to a mating weight, however, emissions intensity was reduced at the same level of profit (Fig.). Increasing the weaning percentage of ewe lambs reduced EIM+W and the relationship was linear and it was the same for both joining weights examined (Fig.). Profit also increased linearly and, as expected profit, was higher at each weaning rate for the lower joining weight.

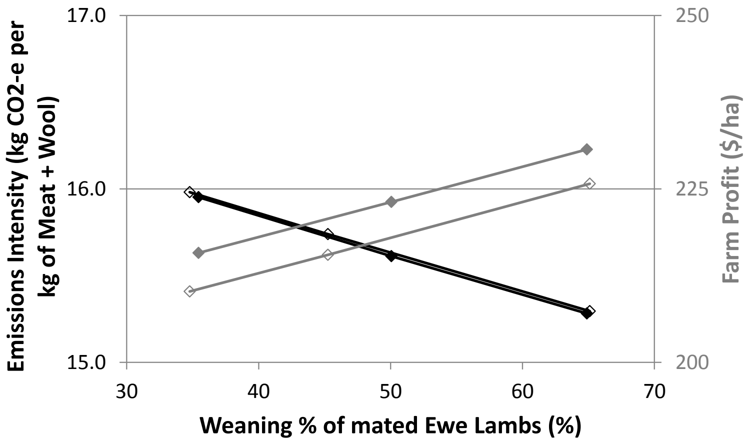

Fig. 11. Increasing the weaning rate achieved from ewe lambs joined at 39 kg (solid) and 42 kg (open) reduces emissions intensity per kilogram of meat and wool (black lines) and increases profitability (grey lines). Weight of the ewe lamb at joining does not affect emissions intensity per kilogram of meat plus wool but does alter profitability.

Survival post-weaning

The improvement in EIM+W was linearly associated with reducing flock mortality beyond weaning (Fig.). The class of stock that contributes to the reduced flock mortality did not alter the slope of the relationship with EIM+W, although the slope of the profit relationship was different for each class of animal. Reducing flock mortality by 1% reduced EIM+W by 0.47 kg CO_2-e/kg Meat + Wool and reducing the mortality of weaners, ewes and wethers individually by 1% reduced EIM+W by 0.121, 0.301 and 0.036 kg CO_2-e/kg Meat + Wool, respectively. Reducing mortality by 1% for weaners, ewes and wethers increased the profitability by $0.86 /weaner, $1.50/ewe and $1.22 /wether.

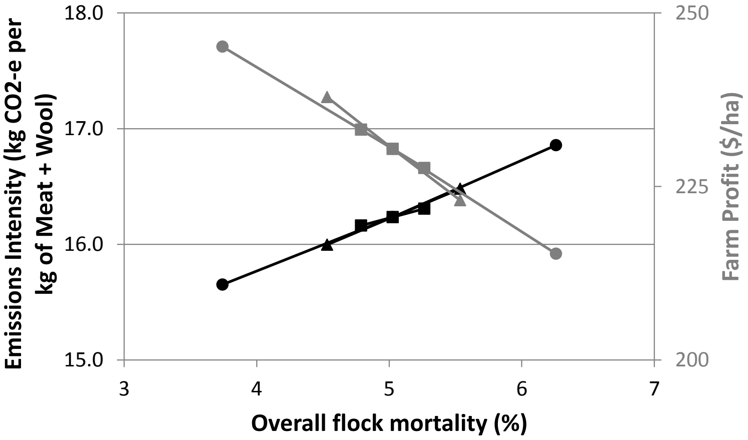

Fig. 12. Reducing mortality (● Ewes, ▲ Weaners, ■ Wethers) reduces emissions intensity per kilogram of meat and wool (black lines) and increases profitability (grey lines) and the class of stock does not alter the relationship between the level of flock mortality and emissions intensity.

Lamb finishing

Increasing the PWWT of the terminal sire by 1 kg as a way to reduce the time to turn-off a finished prime lamb increased profit by $1.43 /lamb and reduced EIM+W by 0.086 kg CO_2-e/kg Meat + Wool (Fig.). This differed to increasing the PWWT of the merino breed, which reduced profit by $2.08 /lamb and leads to little change in EIM+W (-0.008 kg CO_2-e/kg Meat + Wool). Feeding the lambs extra to achieve turn-off weights one week earlier had little effect on EIM+W (0.012 kg CO_2-e/kg Meat + Wool) and increased profit by $1.10 /lamb.

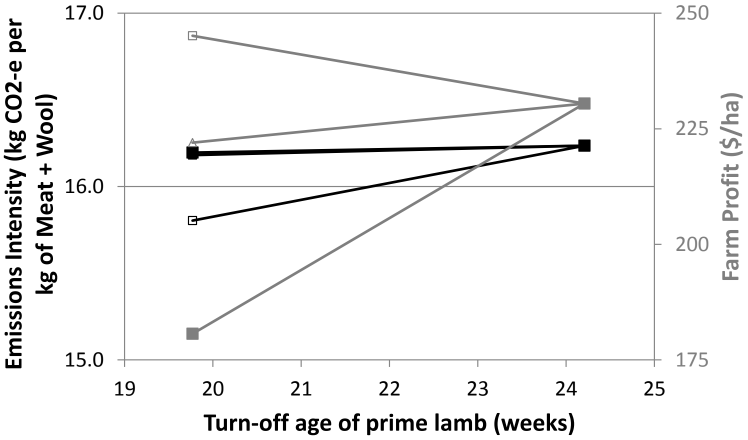

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Fig. 13. The impact on emissions intensity per kilogram of meat and wool (black lines) and profitability (grey lines) of varying the time required to finish prime lambs by varying ■ PPWT of terminal sire, .□ PWWT of the merino, ∆ feeding level of the lamb.

Industry value of critical control points & priorities

The control points associated with increasing scale, pasture growth and pasture utilisation, have the greatest potential to increase profitability at industry level (Table 7). The cumulative impacts of the industry improving from current production levels to the potential realistic levels of these control points would increase profit by $1840 m/yr, however there would be no change in emissions intensity.

Table 7. Calculation of potential increase in aggregated industry-wide farm profit from an increase from current to potential level of the control points.

Control point	Unit	Current level	Potential level	Potential change	Potential change in emissions[H] (mt CO_2-e/yr)	Potential value[I] (m $/yr)
Enterprise scale						
Pasture growth	t/ha	5	7	2	-	1118
Pasture utilisation	%	30	40	10	-	665
Flock structure						
Proportion of terminals	%	29	40	11	-0.35	55
Proportion of wethers	wethers / total sheep	15	10	5	-0.29	28
Reproduction efficiency						
M-M Conception[A]	Lambs scanned/ewe joined	120	140	20	-0.48	81

Control point	Unit	Current level	Potential level	Potential change	Potential change in emissions[H] (mt CO_2-e/yr)	Potential value[I] (m $/yr)
M-TS Conception[A]	Lambs scanned/ewe joined	125	145	20	-0.37	39
Total for conception					-0.85	120
M-M Lamb survival[B]	lambs weaned/lamb scanned	63	75	12	-0.82	154
M-TS Lamb survival[B]	lambs weaned/lamb scanned	68	80	12	-0.60	66
Total for lamb survival					-1.42	220
Mate ewe lambs						
Weaning percentage[C]	Lambs weaned/ewe lamb joined	20	40	3.4[G]	-0.08	10
Proportion mated	Ewe lambs joined/total ewe lambs	3	10	7		
Survival post-weaning						
Weaner survival[D]	Hoggets shorn or sold/lamb weaned	8	3	5	-0.61	42
Ewe survival[E]	Ewes at weaning/ewe joined	6	3	3	-0.91	146

Control point	Unit	Current level	Potential level	Potential change	Potential change in emissions[H] (mt CO_2-e/yr)	Potential value[I] (m $/yr)
Wether survival[F]	Wethers end of year/Wethers start of year	5	2	3	-0.11	28
Total for post-weaning survival					-1.63	216
Lamb finishing						
PWWT Terminal	kg	8	13	5	-0.43	60
PWWT Merino	kg	1 / 8	6 / 13	5	-0.04	-338
Feeding lambs	weeks to turn-off	32	24	8	-0.10	-74

The control points, increasing lamb survival and increasing survival post weaning provided the largest industry gains in both reducing emissions (1.4 and 1.6 mt/yr) and increasing profit ($220 and $216 m/yr). Increasing conception rates of ewes was the second priority and would reduce emissions by 0.8 mt/yr and increase profit by $120 m/yr. The next priorities are reducing the time to turn-off lambs by utilising high growth terminal sires (0.4 mt/yr and $60 m/yr), increasing proportion of ewes mated to terminal sires (0.3 mt/yr and $55 m/yr), reducing the proportion of wethers in the flock (0.3 mt/yr and $28 m/yr) and mating ewe lambs (0.1 mt/yr and $10 m/yr). Increasing the feeding rate of lambs to turn off the finished lamb earlier or increasing the growth potential of merinos both reduced emissions but also reduced profitability.

Phase 2 modelling – ground truthing with experimental data

Increasing the proportion of Biserrula in the diet reduces profit (Figure 1) because increasing the proportion of Biserrula reduces both the optimal number of sheep on the farm and the production per head. The higher the proportion of Biserrula the greater the rate of reduction, between 0 and 20% Biserrula the reduction is $0.35/ha/% of Biserrula and this increases to $1.60 between 60 & 80%. This increasing rate of reduction in profit is because the reduction in sheep numbers increases with higher levels of Biserrula in the diet. At low levels, increasing the proportion of Biserrula substitutes Biserrula for sub-clover and ryegrass and the reduction in profit is due to the lower animal production achieved from Biserrula. However, at higher levels the Biserrula substitutes for grain feeding and this leads to a greater reduction in carrying capacity.

The reduction in emissions intensity with an increasing proportion of Biserrula (**Figure 1**) reflects the reduction in emissions per sheep due to the anti-methanogenic effects of Biserrula. The reduction in total emissions is a reflection of both the reduction in sheep numbers and the reduction in emissions intensity.

Figure 1: Profit (○, $/ha/yr), Total Emissions from the farm (●, kg CO2-e/ha x 100) and Emissions Intensity (- -, kg CO2e/kg meat DW x 10) and the impact of varying the proportion of Biserrula in the diet.

If the voluntary feed intake of dry Biserrula is similarly reduced as for green Biserrula the profitability of including Biserrula in the diet is slightly reduced (**Figure 2**), however, the reduction in profit is much less than the impact from the reduced intake of green feed. Reducing the growth rate of Biserrula by 10% has a moderate impact on farm profitability (**Figure 2**).

These results indicate that the carrying capacity and animal production of anti-methanogenic pastures is critical to their profitability and their likelihood of adoption. The reduction in emissions intensity with increasing levels of Biserrula in the diet is not altered by the productivity of the Biserrula (**Figure 3**), which indicates that the impact on emissions will be mostly associated with the level of adoption of the anti-methanogenic pastures.

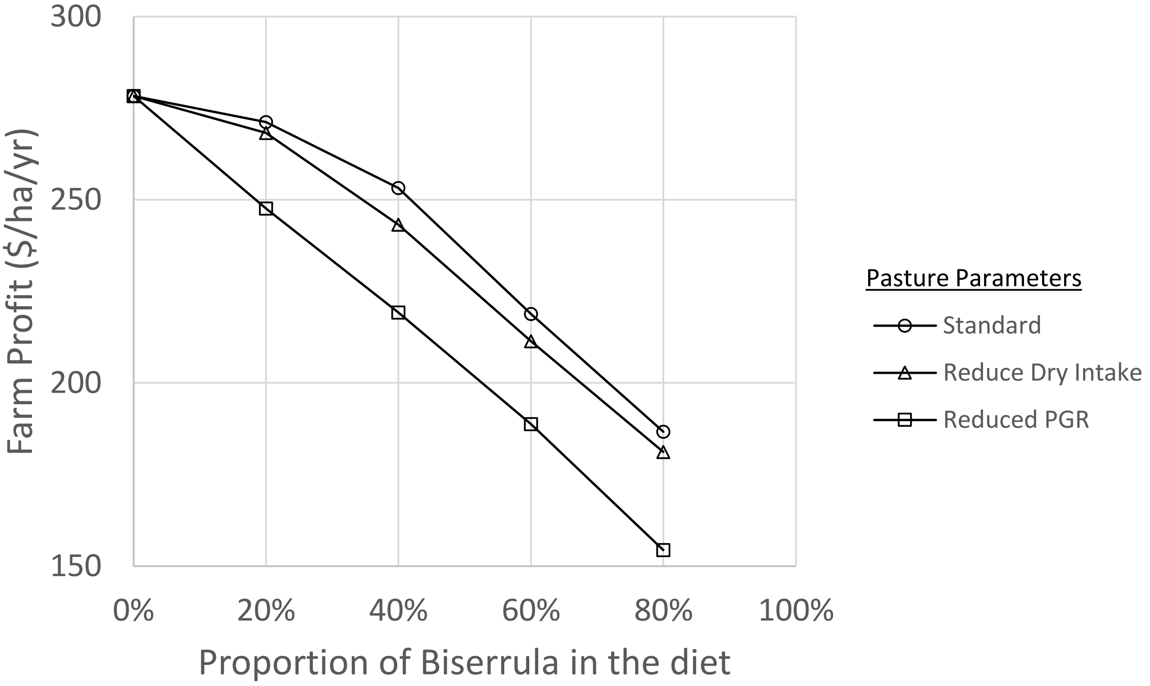

Figure 2: The effect of varying the proportion of Biserrula in the diet on the farm profitability when the growth rate of Biserrula and the voluntary feed intake of dry Biserrula is varied.

Figure 3: There is no effect on the emissions intensity of the farm when the growth rate of Biserrula and the voluntary feed intake of dry Biserrula is varied.

The farm is producing approximately 2.8 kg of CO_2-e/ha so a 10% reduction in emissions increases profitability by about $4/ha if the carbon price is $15/t and the increase is greater for higher carbon prices. Although higher prices for carbon increase profitability at each level of Biserrula in the diet (**Figure 4**), even at $100/t for carbon, profitability is reduced with increasing levels of Biserrula in the diet. This indicates that high prices for carbon cannot compensate farmers for lost production and any technology aimed at reducing emissions will have to do so without reducing farm productivity if it is to be profitable and be widely adopted.

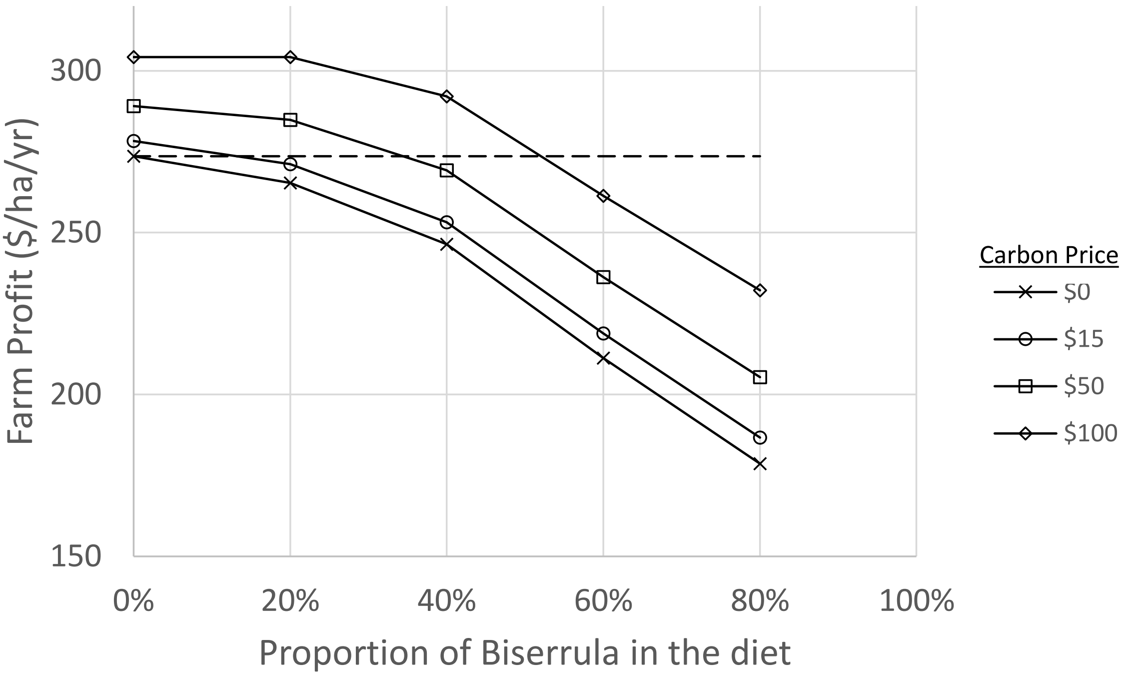

Figure 4: **Impact of the price of carbon ($/t CO2e) on the reduction in profit with higher levels of Biserrula in the diet.**

If the energy that would have been lost as methane can be captured by the animal then profitability is increased at each level of Biserrula in the diet (**Figure 5**). The increase in profitability is similar to receiving an extra $50/t of carbon, so capturing the energy would be a significant payoff in the mitigation in methane.

Figure 5: Impact on profitability of having access to a market for carbon and whether the animals can capture the saved methane energy.

4. Discussion

Reducing greenhouse gas emissions and/or adapting to climate change

This was the first rigorous study to quantify the effect of the low methane potential legume, Biserrula, on methane yield from sheep from the lab to the landscape. Results from previous *in vitro* work and preliminary field work had suggested that Biserrula decreased methane production, but it was unclear whether the effect in the field was due to a direct effect on rumen efficiency or because animals ate less of it, and if the same effect would be seen when the pasture was fed to sheep in the animal house. The two animal house studies in the current project confirmed the potency of Biserrula as an antimethanogenic pasture when fed to sheep as fresh pasture and as hay when fed as the sole component of the diet or as a proportion of the diet. In the second animal house experiment, the incremental inclusion of Biserrula hay improved rumen efficiency and directed the fermentation pathway to propionate production, which is more favourable to methane reduction. The results from the animal house demonstrated that Biserrula has potential to be used as a mixed monoculture pasture with other legumes or grasses in commercial farming systems to reduce methane emissions from sheep without reducing productivity. What remains to be demonstrated is that the effects that we have measured in the lab and in the animal house translate into a commercial grazing scenario. We had anticipated answering this question in this project, but the variability in individual animal methane emissions made it difficult to establish differences between treatments. The difficulties associated with getting an accurate estimate of intake, as well as the impact of factors like the time of grazing and grazing behaviour prior to measurement in the field, are making it difficult to get an accurate representation of what is actually occurring under grazing conditions. This will be a challenge as we move into the future and look to methodologies that can be implemented and accredited for reducing methane emissions.

Although Biserrula was used as the sole component of the diet for some parts of this study, both in the animal house and as a grazing plot in this study, it was never intended to be used in this way commercially because it has been associated with low palatability and photosensitivity when sheep graze it. This was also reflected in the outcomes from the modelling analysis when we made use of our experimental data, which showed that incorporating Biserrula into the farm system to reduce emissions did not increase profit. However, this analysis was simplistic because the representation of the proportion of Biserrula in the diet had the same proportion of Biserrula for the duration of the year and for each class of stock. It is likely that the optimal proportion of Biserrula in the diet could vary through the year and for stock with different growth rates, because we know that Biserrula can be unpalatable to stock at certain physiological states, but nutritionally valuable at other times. Further analysis could be carried out optimising the proportion of Biserrula in the diet during different periods of the year for each class of stock.

The modelling activities in Activity 4 indicate that combining bio-economic modelling and knowledge of the potential on-farm improvements was an effective way to quantify the value of critical control points in the management of sheep emissions. The analysis made it possible to differentiate the potential gains in emissions and the potential gains in profit for the control points. This information can be used to justify expenditure on developing a sheep industry method and used by farmers and their advisers to prioritise on-farm action to reduce emissions and increase profit.

The control points associated with increasing enterprise scale had the largest potential to increase profit, which is consistent with other studies (Alcock 2006, Warn *et al.* 2006, Young *et al.* 2010). However, increasing the scale of the sheep enterprise also increased total emissions and the change in farm profit relative to total emissions was approximately \$200/t of extra CO_2-e. There was a very tight relationship between total emissions from the sheep enterprise and total metabolisable energy intake. This relationship indicates that the level of emissions from the flock will be closely determined by seasonal conditions that dictate total pasture production, the level of utilisation and the quality of the pasture. The results we obtained from our grazing experiments support this in the sense that pasture quality was such a key indicator of emissions. Furthermore, altering the scale of the enterprise through altering pasture production or pasture utilisation rate had very little impact on emissions intensity. This insensitivity of emissions intensity to the scale of the enterprise together with the high value per tonne of total emissions indicates that there is little opportunity for sheep farmers to profit from participating in the ERF through altering the scale of their enterprise.

The areas that have the highest potential to reduce emissions and increase profit are improving lamb survival and improving survival post-weaning. The next highest priority areas are improving scanning rate of ewes and increasing the growth potential of terminal sires. The second order priorities are increasing the proportion of ewes mated to terminal sires, reducing the proportion of wethers in the flock and mating ewe lambs. The information necessary for farmers to implement the management to achieve higher lamb survival, higher conception rates, lower ewe and weaner mortality is available through industry training programmes such as Lifetime Ewe Management and High Performance Weaners (Rural Industries Skills Training, Hamilton, Victoria). MIDAS is a deterministic, comparative static general equilibrium model and the variation in seasonal conditions and the size and composition of the flock due to varying carrying capacity between years is not represented. Nonetheless, we believe that the model will accurately represent the overall level of emissions and the emissions intensity achieved in the medium term from farms implementing the different management options analysed, Therefore, using this type of model to rank the most profitable critical control points is valid for the technology examined.

Carbon Farming Initiative/Emissions Reduction Fund methodology development

Increasing productivity

Increased animal productivity was clearly and consistently demonstrated through the use of high quality legume pastures. In addition, the use of a “choice” legume and ryegrass pasture improved rumen efficiency compared to a ryegrass monoculture pasture. It is known that when sheep are offered a choice between legume and grass they consistently choose 70% legume to 30% grass. In the current study the sheep offered the “choice” pasture in WA had growth rates equal to those offered legume monocultures and higher than the sheep offered the ryegrass monoculture. This infers that grass pastures can be included in legume-based systems without causing a loss in production.

What was consistently observed throughout this project was that the key driver of methane and animal productivity was pasture quality. High digestibility and low fibre feed reduced methane yields and methane intensity and increased productivity. This is a clear message to disseminate to farmers to reinforce good management practices. Managing pastures and grazing techniques to maintain high quality feed improves rumen efficiency and ultimately animal productivity. The grazing studies over two seasons in Victoria supported the major findings in WA that methane production is driven by nutritional qualities of the pasture. High digestibility and low fibre legume pastures tended to produce less methane and higher animal growth rates compared to perennial ryegrass. Consecutive growing seasons of low and variable rainfall in Victoria made it difficult to establish pastures and reduced the potential yields. Despite this, our findings in WA and Victoria support other research findings and can be used to inform the development of ERF methodology for methane abatement from whole farm systems. Our animal house data indicates that it should be possible to build a methodology around incorporating a lower methane emitting pasture species/variety into the feedbase and reduce emissions. However, without evidence that this is reflected in the field under grazing conditions may make it difficult to finalise a complete an application for that methodology. In contrast, there is evidence from our work that suggests clear guidelines on pasture and grazing management to maintain the highest quality pasture could be developed into a systems-based methodology. A pasture species with a direct antimethanogenic effect (eg. biserrula) could be incorporated into that systems-based methodology. Our bio-economic modelling results indicate that the carrying capacity and animal production of anti-methanogenic pastures is critical to their profitability and their likelihood of adoption. The reduction in emissions intensity with increasing levels of Biserrula in the diet is not altered by the productivity of the Biserrula, which indicates that the impact on emissions will be mostly associated with the level of adoption of the anti-methanogenic pastures.

Our bio-economic modelling analysis showed that when the flock structure, reproduction efficiency, survival post-weaning and lamb finishing control points were varied there was no relationship between whole farm profit and total emissions. However, emissions intensity did change and the correlation between profit and EIM+W was favourable for the majority of the control points. This indicates that if a method similar to the beef cattle herd management method, which uses change in emissions intensity multiplied by level of production as the basis of calculating the reduction in emissions, was to be developed for the sheep enterprise there would be potential for sheep farmers to be involved in the ERF and to concurrently increase profit. The potential for the sheep industry to reduce emissions through existing information and management options is up to 5 mt/yr and there is motivation, through increased profit, for farmers to adopt the management. This quantification of the potential level of reduction from the sheep enterprise may justify the development of a method for extensive sheep production enterprises.

Sustainable land use

Legume pastures of high quality and low methane potential will ultimately improve the sustainability of land use particularly in mixed cropping systems; by fixing nitrogen in the soil and reducing the need for application of synthetic chemicals. In addition, hard seeded legumes such as Biserrula have additional benefits including methane abatement, weed control in ley cropping systems, and regeneration in multiple seasons from a seedbank. The strategic use of “choice” pastures can potentially optimise productivity and reduce methane. This will improve the sustainability of land use by increasing per hectare profitability without increasing methane emissions.

How this research contributed to the aim and expected outcome of the project.

Information was generated and statistically analysed from animal house experiments, grazing trials over two growing seasons in two location, and *in vitro* batch culture fermentations using pasture samples from each *in vivo* experiment. These analyses quantified the production and methane potential of the pasture treatments we tested. The information was used to ‘ground truth’ the MIDAS model and provided inputs into whole-farm modelling to assess a range of sheep and pasture management strategies on whole farm profit, risk and methane emissions for different environments and climate change scenarios. The outputs from the modelling indicate that if a method similar to the beef cattle herd management method, which uses change in emissions intensity multiplied by level of production as the basis of calculating the reduction in emissions, was to be developed for the sheep enterprise there would be potential for sheep farmers to be involved in the ERF and to concurrently increase profit. We also identified that the areas that have the highest potential to reduce emissions and increase profit are improving lamb survival and improving survival post-weaning. The information necessary for farmers to implement the management to achieve higher lamb survival, higher conception rates, lower ewe and weaner mortality is available and the quality of the feedbase as well as genetic selection are both strategies to optimise these key drivers.

5. Future research needs

Unanswered questions and areas for future work

There are two main areas where the research questions were only partially answered. First, the efficacy of Biserrula as a low methane pasture still needs to be confirmed. There was a consistent, obvious and potent effect of Biserrula on methane yield *in vitro* and in the animal house when the sheep were fed maintenance rations. This effect was likely to be due to secondary compounds contained in Biserrula that inhibit the growth of methanogens in the rumen. The active compounds are being isolated at the School of Biochemistry at UWA using an in vitro screening technique, and comparing them to the compounds responsible for the antimethanogenic properties could help direct breeding programs for new varieties that improve both productivity and emission reduction properties of Biserrula.

However, the effectiveness of Biserrula was not obvious in the plot scale experiments when the sheep were offered *ad libitum* levels of pasture. The reasons for the lack of effect in the field remain unclear, but are most likely related to variability between animals, grazing behaviour, methane release, feed intake, time of grazing prior to measurement, sampling time of day and sampling day. All of these things are easy to measure or control in the animal house and respiration chambers, but add considerable variability to measurements in the field and under grazing conditions. The intention is to use Biserrula as a pasture mix, not as a monoculture, to optimise animal performance and reduce methane emissions. Future work needs to be done using Biserrula in a “choice” pasture to compare feed efficiencies and methane production compared with traditional pasture systems and also to establish a more accurate protocol for accounting for variability in emissions and intake in-field.

Second, at Ridgefield the “choice” pasture in the plot-scale grazing work improved rumen efficiency compared to ryegrass pasture and was reflected in higher daily live weight gains in the sheep. However, there was no observed difference in methane intensity. This is most likely because the feed quality of all pastures was high resulting in relatively low methane emissions from all pastures in 2015 and the fact that feed intake was *ad libitum*. This is supported further when comparing the Victorian data with the WA data. The methane intensities were higher in Victoria than in WA and probably resulted from a lower quality feed base. Further work needs to be done to demonstrate improved feed efficiency, lower methane intensity and increased whole-farm profitability from “choice” pastures and high quality pastures compared to systems using low quality feeds/pastures. The main challenge is to establish accurate measurements from grazing animals.

Our modelling analysis showed that incorporating Biserrula into the farm system to reduce emissions did not increase profit. However, the analysis was simplistic because we had limited field data on the impact of using Biserrula as a mix rather than a monoculture. The representation of the proportion of Biserrula in the diet had the same proportion of Biserrula for the duration of the year and for each class of stock. It is likely that the optimal proportion of Biserrula in the diet could vary through the year and for stock with different growth rates. Further analysis could be carried out optimising the proportion of Biserrula in the diet during different periods of the year for each class of stock. Currently there are no methods available for sheep producers to be credited with ACCUs by mitigating methane emissions from their sheep. However, if methods were developed along similar lines to the beef management guidelines, then breeding sheep to reduce emission shows a moderate payoff and further investigation of the relative economic value of methane yield is warranted in order to develop breeding objectives for sheep producers. The assumptions that we made about the low methane genotype did not represent the different genotypes that would result from breeders selecting animals with different emphasis on methane yield. The genetic parameters necessary to calculate these responses will soon be available from the genetics and feed efficiency projects within the RPP project, so further analysis could be carried out to quantify the profitability of utilising some selection pressure to breed for reduced methane yield.

6. Publications

Peer reviewed work:

- Honours thesis (2015), Madison Corlett, Supervisors Peter Hutton, Andrew Thompson

  Title: Including Biserrula chaff in the diet of sheep.
- Masters thesis (2015), Mankeane Monica Mofoti. Supervisors: Peter Hutton and Zoey Durmic. *Title:* Relationships between *in vitro* and *in vivo* methane emissions from fermented pasture hays.

Two page conference papers:

- Muir, S.K., A.J. Kennedy, A.N. Thompson, P. Hutton, P. Vercoe, J, Hill and G. Kearney (2016), Offering legume based pastures to sheep reduced methane emissions and increased growth rates compared with perennial ryegrass pastures in spring and summer. Animal Production in Australia, Proceedings of the 31st Biennial Conference of the Australian Society of Animal Production, July 4-7 2016 Adelaide Australia. p 63. (http://www.asap.asn.au/wp-content/uploads/abstract-2015/179/attach_brief.pdf)

One page conference papers:

- Hutton, P.G., Lund, K., Toovey, A., Phillips, N., Allington, T., Paganoni, B., Vercoe, P.E., Thompson, A.N. (2014) Biserulla reduces methane production from sheep when compared to other commercial legume pastures, Proceedings of the 30th Biennial Conference of the Australian Society of Animal Production, Canberra.

Poster presentations at National/International conferences:

- Hutton, P.G., Macleay, C.A., Jones, C., Muir, S., Kearney, G., Vercoe, P.E., Thompson, A.N. (2016) Providing pasture choice to sheep reduced intensity of methane emissions and increased growth compared with annual ryegrass. Proceedings of the 31st Biennial Conference of the Australian Society of Animal Production (http://www.asap.asn.au/wp-content/uploads/abstract-2015/144/attach_brief.pdf)
- P. Hutton, J. Vadhanabhuti, A.N. Thompson, D. Blache, P.E. Vercoe (2016) Biserrula pelecinus reduces leptin secretion in dry merino ewes. Proceedings of the 31st Biennial Conference of the Australian Society of Animal Production (http://www.asap.asn.au/wp-content/uploads/abstract-2015/230/attach_brief.pdf)
- Hutton, P.G., Lund, K., Thompson, A.N., Vercoe , P.E. (2016) Legumes with low methane potential in vitro can lower in vivo methane yield in sheep. Proceedings of the 6th Greenhouse Gases and Animals in Agriculture Conference, Melbourne
- Young JM, Thompson AN, Trompf J, Vercoe PE (2016). Critical control point analysis of methane emissions on southern Australian sheep farms to prioritise on farm actions to reduce emissions and improve profitability. Proceedings of the 6th Greenhouse Gas in Animal Agriculture conference, Melbourne, Poster PO203:

Student presentation: Madison Corlett. (2016) presented the paper:

- Corlett, M., PE Vercoe, A. Thompson, P. Hutton (2016) Including Biserrula chaff in the diet of sheep reduced methane yield on the basis of energy intake. 31st Biennial Conference of the Australian Society of Animal Production. (http://www.asap.asn.au/wp-content/uploads/abstract-2015/216/attach_brief.pdf)

Draft publications for submission:

- Revised publication submission to AFST. *Biserrula pelecinus* reduces methane yield from sheep compared to other pasture legumes. P Hutton, K.E. Lund, P.E. Vercoe, A.N. Thompson
- Including Biserrula chaff in the diet of sheep reduced methane yield on the basis of energy intake. M. Corlett, P.E. Vercoe, A.N. Thompson, P. Hutton. To be submitted to AFST
- Effect of legume and ryegrass pastures on methane intensity in sheep. P. Hutton, C.A. Macleay, C. Jones, S. Muir, G. Kearney, P.E. Vercoe, A.N. Thompson. To be submitted to AFST.
- Young JM, Thompson AN, Trompf J, Vercoe PE (2016). Critical control point analysis of methane emissions on southern Australian sheep farms to prioritise on farm actions to reduce

emissions and improve profitability. Submitted to Animal Production Systems and under revision prior to resubmission

Other press coverage:

- Kondinin Group's Farming Ahead, media release, April 2016. With pressure mounting on producers to minimise methane emissions from livestock, help may be as close as the nearest ryegrass pasture. By Jill Griffiths
- Agriculture Victoria Factsheet, 2016. Low methane forages.
- UWA Future Farm, 2015 Open Day
- Lead organisation website: Department of Agriculture and Water Management FTRG round 2

7. Appendix

Abstracts referred to in Section C (b):

Biserrula pelecinus reduces methane yield from sheep compared to other pasture legumes

P Hutton [a, b, *], K.E. Lund [a], P.E. Vercoe [a, c], A.N. Thompson [b]

(ready for submission to Animal Feed Science and Technology)

Abstract

Legume pastures with low methane potential included in traditional sheep grazing systems have potential to reduce total methane emissions (CH_4/day) and methane yield (CH_4/intake). Biserrula pelecinus is consistently the most anti-methanogenic pasture legume we have identified in vitro. We tested the hypothesis that sheep consuming Biserrula would have lower methane yields compared to other legume species. Daily feed intake, live weight change, 23 h methane production measured in respiration chambers, and volatile fatty acid and ammonia concentrations in rumen fluid were measured from individual sheep (n=62) offered freshly cut bladder clover (Trifolium spumosum), subterranean clover (Trifolium subterranean), serradella (Ornothopus sativas), and Biserrula (Biserrula pelecinus) pasture as their sole diet under animal house conditions. The sheep fed Biserrula had lower methane yield relative to serradella, bladder clover and subterranean clover and on the basis of dry matter intake (11.4, 14.3, 14.3, and 14, g CH_4/kg respectively: P<0.05) and per unit intake of digestible energy (0.57, 0.77, 1.10, 1.17, 1.10 g/MJ respectively; P<0.05). The more indigestible cell wall components, cellulose and lignin, were strongly correlated (0.43) with methane production. It is also likely, based on findings from previous work that secondary compounds contained in Biserrula inhibited methanogenesis. Biserrula reduces methane yield and may be useful in mixed forage systems.

Keywords: Methane yield, grazing systems, secondary compounds.

Critical control point analysis of methane emissions on southern Australian sheep farms to prioritise on farm actions to reduce emissions and improve profitability

J. M. Young[aE], A. N. Thompson[B], J. Trompf[C] and P. E. Vercoe[D]

(Submitted to Animal Production Systems – currently responding to reviewers comments)

Abstract

Enteric methane emissions from sheep contribute approximately 2% of Australia's national greenhouse gas emissions. This indicates that there could be potential for sheep farmers to contribute to reducing national emissions by participating in the Emissions Reduction Fund if an approved method was developed. If a method was developed, farmers and their advisers would need to prioritise the management they would implement to reduce emissions and emissions intensity. Prioritising would require an understanding of the capacity to change and the impact of the different management strategies and technologies on both profitability and the level of emissions and emission intensity. The analysis described in this paper initially used whole farm systems modelling to quantify the changes in profitability and emissions from adopting 17 different technologies relating to enterprise scale, flock structure, reproduction efficiency, flock mortality and lamb finishing. It then quantified the potential industry gain in each control point and combined this and the MIDAS-calculated values to determine the total industry potential. The control points, increasing lamb survival and increasing survival post weaning provided the largest industry gains in both reducing emissions (1.4 and 1.6 mt/yr) and increasing profit ($220 and $216 m/yr). Increasing conception rates of ewes was the second priority and would reduce emissions by 0.8 mt/yr and increase profit by $120 m/yr. The next priorities are reducing the time to turn-off lambs by utilising high growth terminal sires (0.4 mt/yr and $60 m/yr), increasing proportion of ewes mated to terminal sires (0.3 mt/yr and $55 m/yr), reducing the proportion of wethers in the flock (0.3 mt/yr and $28 m/yr) and mating ewe lambs (0.1 mt/yr and $10 m/yr). Increasing the feeding rate of lambs to turn off the finished lamb quicker or increasing the growth potential of merinos both reduce emissions but also reduce profitability. The results show that combining bio-economic modelling and knowledge of the potential on-farm improvements was an effective way to quantify the value of critical control points in sheep-emissions management. The analysis described can be used to justify expenditure on developing a sheep industry method and could be utilised by farmers and their advisers to prioritise on-farm action to reduce emissions and increase profit.

Additional keywords: merino, MIDAS, profit.

Effect of legume and ryegrass pastures on methane intensity in sheep

P. Hutton[1,2], C.A. Macleay[3], C. Jones[1], S. Muir[4], G. Kearney[5], P.E. Vercoe[2,6], A.N. Thompson[1]

(Prepared for submission to Animal Feed Science and Technology)

Abstract

In grazing systems, methane yield and emissions intensity can be lowered by improving the metabolic efficiency in the rumen using pastures with high nutritive values and/or grazing pastures containing secondary compounds that inhibit methanogenesis in the rumen. Sheep that graze legumes often have greater growth performance and produce less daily methane compared to those grazing grasses. Managing pastures to maintain a higher proportion of legumes is therefore a strategy that farmers could adopt to reduce emissions intensity, but this can be difficult during winter. Spatially arranging legume/grass monocultures in a side-by-side ‘choice’ fashion can be easier to manage and can be as effective on animal performance as legume monocultures. The objective of this study was to examine the potential of Biserrula and a legume/grass choice pasture under grazing conditions to maintain or

increase growth rates and reduce methane emissions compared with monoculture pastures of annual ryegrass or legumes. Ten groups of 24 dry merino ewes were offered unrestricted grazing on duplicate plots of annual ryegrass (ARG), subterranean clover (Sub), side-by-side monocultures of annual ryegrass and subterranean clover (Choice), serradella (Serr) and Biserrula (Bis) over two spring growing seasons. Methane was measured fortnightly from individual sheep using portable accumulation chambers. Daily weight gains from the Choice pastures were equivalent to those from Sub pastures and higher than from ARG. Methane intensity tended to be lowest from the choice pasture but tis was not significicant. Choice pastures can potentially improve sheep production and reduce the impact of greenhouse gas emissions by improving the efficiency of conversion of pasture into growth.