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Mitigation of methane emissions from the northern beef herd

Using open-path lasers to acquire direct measurements of methane emissions from cattle grazing northern pastures

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Abstract

Methane (CH_4) emissions associated with beef production systems in northern Australia are yet to be quantified. Methodologies are available to measure individual emissions, but application in extensive grazing environments is challenging.

A micrometeorological methodology for estimating herd scale emissions using an indirect open-path spectroscopic technique and an atmospheric dispersion model is described. Livestock emissions have been measured for properties in Queensland and Northern Territory. In addition, 22 diets, combining tropical grass and legume species, have been fed to cattle under animal house conditions and CH_4 emissions measured using open-circuit respiration chambers.

Daily mean (± sem) CH_4 emissions from the study sites ranged from 136 ± 21.5 g/hd/d to 281 ± 22.3 g/hd/d. Low emissions were associated with young steers grazing irrigated and fertilised Rhodes grass. High emissions were associated with mature Brahman cows and heavier steers grazing Buffel/Sabi grass pasture. Animal house studies indicated that CH_4 production could be predicted as 19.6 g/kg forage dry matter intake. Mean CH_4 emission rates across all diets were ~ 5.2–7.2% of gross energy intake which compare favourably with IPCC (2006) for large ruminants fed low-quality crop residues and by-products. Methane emission values for mixed diets have been characterised and can be benchmarked in grazing systems across northern Australia using the dispersion methodology.

Executive Summary

Methane (CH_4) emissions from cattle grazing pastures characteristic of northern Australia are yet to be reliably quantified. Poor quality pastures, marked seasonal rainfall and low animal productivity are characteristic of northern Australia, but are also associated with high methane (CH_4) emissions intensity/unit animal product.

Currently a number of methodologies are available to measure individual animal emissions; respiration chambers, SF_6 (sulphur hexafluoride) tracer technique, or have been suggested; blood methane concentrations, whole body thermography, but these are difficult to use other than at an individual animal level and not applicable to estimating emissions for extensive grazing environments. Northern subtropical and tropical regions account for 54.5% of the national beef cattle herd. The smallest unit of measure to characterise livestock greenhouse gas (GHG) emissions across land and pasture types, bio-agronomic regions and or seasons may be at the herd scale. An on farm methodology is required to generate reliable baseline emission data and to assess the effect of mitigation activities at the herd scale. There are no suitable methods for measuring emissions for the northern beef herd, yet measurement is a critical component for mitigation and a carbon farming framework. This project was conducted to address this deficiency.

Expected outcomes of the project were:

- validated direct and indirect methods of measuring methane emissions from cattle under northern Australian grazing conditions
- improved understanding of the possible anti-methanogenic properties of important tropical legume plants widely used in northern Australia to improve beef productivity
- proof of concept to enable methane emissions benchmarking to the level required for carbon accounting systems.

This report details the validation and application of a methodology for estimating CH_4 emissions at the herd scale using an open-path spectroscopic technique and a backward Lagrangian Stochastic (bLS) dispersion model. Inputs for this model included wind speed, direction, atmospheric turbulence data and line-averaged concentrations of CH_4 determined with an open-path laser to generate a series of unique herd scale data sets for 246 cattle including steers, cows and heifers grazing northern pastures.

Measurements were taken on properties across central and northern Queensland and the Northern Territory for a total of 98 days. In addition, methane production from 13 Brahman steers (mean ± sem liveweight; LW 227 ± 6.2 kg) maintained under animal house conditions and offered 22 diets from combinations of five tropical grass species and five legumes, with a minimum of three steers per diet, was measured using open-circuit respiration chambers.

Daily mean (± sem) CH_4 emissions associated with five sites across northern Queensland and the Northern Territory ranged from 136 ± 21.5 g/hd/d for steers grazing an irrigated Rhodes grass pasture to 281 ± 22.3 g/hd/d for Brahman cows grazing a Buffel/ Sabi grass pastures. The lowest emissions were associated with young steers grazing an irrigated and improved pasture fertilised with urea (150 kg/ha) and managed intensively. In comparison, the higher CH_4 emissions were associated with mature Brahman cows and heavier steers (LW> 200 kg) grazing either Buffel or Sabi grass dominated pastures, respectively. Methane emissions were within the range of values previously suggested for steers grazing improved and native pastures (Hunter 2007 and McCrabb *et al.*, 1997), although generally higher than the values reported by Kennedy and Charmley (2012) for hay diets ranging from Spear grass (53.9 ± 4.44 g CH_4/d) to Buffel grass (159 ± 13.7 g CH_4/d) fed to steers under animal house conditions. Emission values, determined using an open-path spectroscopic technique and bLS dispersion model, similar to current IPCC Tier I emission factors (IPCC 2006) were limited to Brahman cross heifers grazing predominantly Native couch (*Brachyachne* sp.) and Golden Beardgrass (*Chrysopogon fallax)* dominated pastures indicating that current values used for national inventory purposes are only representative of a small portion of the northern beef herd.

This study was not conducted to assess emission reductions on each site although data collected in the field using an open-path spectroscopic technique/bLS dispersion method could populate a methane model to investigate mitigation outcomes. Emissions at the farm scale will vary depending on pasture type, seasonality and class of ruminant livestock, making the usefulness of herd scale emission data invaluable for national inventories, when a large number of properties can be captured in a series of measurement campaigns.

Measurement opportunities that complement normal animal behaviour will be crucial in ensuring a low input methodology for extensive grazing environments. Further development of equipment rather than the methodology is required to have this technology more widely adopted by the industry. Developing a system that interfaces with current technology such as electronic identification systems (EIDs) to identify individual animals and source intensity (number of animals measured) will be beneficial and support long term measurements.

Contents

1 1. Background

Australia's northern rangelands are dominated by beef production and extensive grazing systems generate about 4 % of northern Australia's total value of agricultural production (ABARE, 2007). Northern subtropical and tropical regions maintain 14.5 x 10^6 or 54.5 % of the 26.6 x 10^6 national beef cattle herd (MLA 2011, Charmley *et al*., 2008). Across these regions pastures are large, often > 120 km^2 (Hunt *et al*., 2007), and are dominated by C4 grasses, which generally have lower nutritional value than temperate grasses (Wilson, 1994). Poor soils and marked seasonal rainfall support a wide range of native and introduced grasses, legumes and forbs. This range of pasture communities, in association with mixed soil types, contributes to marked heterogeneity in unimproved and improved grazing systems. In addition, seasonal fluctuations in rainfall affect available forage biomass and digestibility. Heterogeneous pastures are inherently difficult to manage due to marked seasonal growth and selection by livestock for palatable pasture species (O'Reagain and Turner 1992). Consequently, animal management to optimize animal production while reducing enteric methane emissions from these pastoral systems requires consideration of feed availability and forage quality. Low pasture digestibility can be associated with low animal productivity and high CH_4 output/unit product or per unit dry matter (DM) intake (Johnson and Johnson, 1995). Patch grazing in heterogeneous rangelands is inevitable; some areas are over-grazed while other areas are under-grazed (O'Reagain, 2001) and cattle may experience prolonged live weight (LW) stasis, loss, or compensatory growth throughout their lifetime (Tomkins *et al*., 2006), which impacts achieving target slaughter weight and lifetime CH_4 production (Charmley *et al*., 2008).

Methane from farmed livestock accounts for ~10.7 % (CO_2-e) of Australia's total Greenhouse Gas (GHG) emissions (AGEIS, 2008) of which almost 95% originate from enteric sources. Factors affecting CH_4 production are poorly understood for Australia's northern beef production systems (Charmley *et al*., 2008), reflecting the limited number of studies conducted on enteric CH_4 emissions from cattle fed tropical forages (McCrabb and Hunter, 1999). Current estimates are derived from Intergovernmental Panel of Climate Change (IPCC, 2006) methodologies or predictive algorithms, based on animal and dietary factors, using large data sets from dairy and beef cattle (Ellis *et al*., 2007, Yan *et al*., 2009).

Emissions from beef production systems characteristic of northern Australia are considered to be higher than cattle grazing improved pastures in temperate regions and there is a positive relationship between enteric methane production and DM intake (Kurihara *et al*., 1999, Hunter 2007). Charmley *et al*., (2008) describe a modelling approach specific to northern Australia (Northern Australia beef cattle energetics and methane simulator; NABCEMS) which estimates cattle CH_4 emissions for bioregions by linking a metabolisable energy (ME) based animal production model to a property herd economic model. Beef cattle grazing rangelands of widely varying quality can be assumed to produce up to 60 kg CH_4/hd/year, or approximately 164 g/d (Tier I; IPCC 2006), but this value is applied to cows, bulls and young animals regardless of seasonal variability and is used in national GHG inventories. Charmley *et al*., (2008) indicate that un-supplemented Brahman cows may produce up to 405 g CH_4/d whereas McCrabb *et al*., (1997) reports emission values of 212 g/d for Brahman steers fed long-chopped Angleton grass (*Dicanthium aristatum*) supplemented with 500g/d cotton seed meal. Emission rates between classes of livestock are apparent and similarly diet has a significant effect; Hunter (2007) reports methane production by Brahman crossbred steers to range from 94.5 to 215 g/d for Angleton or Rhodes grass diets, respectively. Consequently, CH_4 measurements from the northern herd and for specific production systems are yet to be reliably quantified.

Achieving reductions in enteric CH_4 emissions from farmed ruminant livestock, particularly beef cattle, is an industry target given anticipated corresponding increases in production efficiency and environmental benefits in carbon constrained production systems. It is possible that mitigation activities suitable for beef production in northern Australia could achieve the greatest environmental and economic returns, but it is first necessary to acquire reliable baseline emission data to assess the effect of mitigation activities at a farm or regional scale.

Major abatement of emission intensities (as t CH_4/t LW gain) are required if Australia's northern beef industry is to contribute to national reductions in GHG emissions under any proposed Australian legislation for a Carbon Pollution Reduction Scheme. In November 2011 the Australian federal parliament passed the Clean Energy legislation which aims to reduce carbon pollution by 160 x 10^6 t by 2020. This legislation excluded agriculture; however it is now economically and practically prudent for the agricultural sector, including livestock, to be developing methods capable of accounting for all the carbon produced, stored and emitted by each production system.

Direct measures of individual animal CH_4 emissions using open circuit respiration chambers or the sulphur hexafluoride (SF_6) tracer technique (Ellis *et al.,* 2007; Yan *et al*., 2009) require considerable investment in infrastructure, technical support and may impact animal feeding behaviour. Consequently, only a limited number of individual animals are monitored in any one study and correction factors are required to calculate actual CH_4 emission values. National inventories require accurate CH_4 emission measurements from whole farm systems (McGinn *et al*., 2008) based on geography, management (including mitigation strategies) and seasonal influences. An indirect micrometeorological methodology based on inverse dispersion (Flesch *et al.,* 2005) has been shown to have potential for estimating CH_4 emissions from feedlot and grazing production systems (Laubach *et al*., 2005a, 2005b; Loh *et al*., 2008; McGinn *et al*., 2007, 2008), but has yet to be trialled across a number of grazing systems to determine the suitability of this technique for northern Australia.

The principal objectives of this project were to validate an open-path laser technique using open-circuit respiration chambers, apply that technique across a number of grazing environments and determine the application of the technique in monitoring and mitigation practices targeting methane emissions from the northern beef herd.

2 2. Project Objectives

This report details the findings of a project conducted to validate an open-path laser technique using open-circuit respiration chambers, apply that technique across a number of grazing environments and determine the application of the technique in monitoring and mitigation practices targeting methane emissions from the northern beef herd.

To achieve these objectives a series of experiments were conducted under animal house conditions (Kennedy and Charmley, 2012) and in grazing environments. One experiment was conducted to compare methane emissions from Brahman steers grazing or fed Rhodes grass (*C. gayana*) using an indirect open-path spectroscopic technique / bLS dispersion model or open-circuit respiration chambers, respectively (Tomkins *et al.,* 2011). In addition, five campaigns were conducted across northern

Australia using an indirect open-path spectroscopic technique / bLS dispersion model methodology to obtain direct emission values from cattle grazing distinct pastures.

Project objectives were:

- Complete calorimetry measurements of methane emissions from *Bos indicus* cattle fed diets of three tropical legume species
- Complete validation of laser technique against calorimetry (open-circuit respiration chambers)
- Collaborate with UWA with in-vitro measurements of changes in methane emissions induced by legume species
- Complete field (commercial) scale evaluation of laser and sensor methodology measurement technology in at least four contrasting northern production systems

Expected outcomes of the project were:

- validated direct and indirect methods of measuring methane emissions from cattle under northern Australian grazing conditions
- improved understanding of the possible anti-methanogenic properties of important tropical legume plants widely used in northern Australia to improve beef productivity
- proof of concept to enable methane emissions benchmarking to the level required for carbon accounting systems.

3 3. Methodology

3.1 3.1 Application of laser technique to large paddocks; study sites

3.1.1 Belmont Research Station, Queensland

Two field studies were conducted at CSIRO Belmont Research Station (lat 23.213° S; long 150.390° E), near Rockhampton Australia. The average annual minimum and maximum temperatures at the site are 16.6 °C and 28.3 °C, respectively. Average annual rainfall is 759 mm. The first study was conducted in 2009 and involved validating an indirect open-path spectroscopic technique / bLS dispersion model against open-circuit respiration chambers when animals grazed or were fed irrigated Rhodes grass (*Chloris gayana*) from dedicated paddocks on Belmont Research Station.

The second study was conducted in 2011. Methane emissions from animals grazing a mixed sward dominated by *C.gayana*, *Urochloa mosambiensis* and *Bothriochloa* sp. were measured using an indirect open-path spectroscopic technique/bLS dispersion model methodology only.

3.1.2 Lansdown Research Station, Queensland

One field study was conducted at CSIRO Lansdown Research Station (lat 19.657° S; lon 146.837° E), near Townsville Australia. The average annual minimum and maximum temperatures at the site are 16.6 °C and 25.9 °C, respectively, and the average annual rainfall (1975-2008) is 809 mm. Methane emissions from animals grazing a mixed sward dominated by *Urochloa mosambiensis* and *Siratro* sp. were measured using an indirect open-path spectroscopic technique / bLS dispersion model methodology only.

3.1.3 Douglas Daly Research Farm, Northern Territory

One field study was conducted at the Northern Territory Government Department of Resources Douglas Daly Research Farm (lat 13.833° S; lon 131.186° E) Australia in October – November 2010. The average annual minimum and maximum temperatures are 29.1 °C, and 34.2 °C, respectively. Annual average (42 year mean) rainfall is 1200 mm falling between October and April. Methane emissions from animals grazing an improved pasture dominated by *Cenchrus ciliaris* and *Urochloa mosambiensis* were measured using an indirect open-path spectroscopic technique/ bLS dispersion model methodology only.

3.1.4 Kidman Springs Research Station, Northern Territory

One field study was conducted at the Northern Territory Government Department of Resources Kidman Springs Research Station (lat 16.116° S; lon 130.956° E) Australia in August 2011. The average annual minimum and maximum temperatures are 20.2 °C, and 34.9 °C, respectively. This region has a hot, seasonally dry monsoonal climate. Average annual rainfall is 680 mm, with most rain falling between December and March. Methane emissions from animals grazing an open woodland pasture of *Bauhinia* sp. dominated by Native couch (*Brachyachne* sp.), Golden Beardgrass (*Chrysopogon fallax*) and Mitchell grass (*Astrebla* sp.) were measured using an indirect open-path spectroscopic technique/ bLS dispersion model methodology only.

3.2 3.2 Animals and grazing management

The experimental protocol complied with the Australian Code of Practice for the care and use of Animals for Scientific Purposes (NHMRC, 2004) and was approved by the organisational Animal Experimentation and Ethics Committee (RH259/09 and A4/2010). Table 1 summarises descriptors for animals and pastures at each study site.

3.2.1 *Belmont Research Station, Queensland*

Eighteen beef steers; nine Brahman (*B. indicus*) and nine Belmont Red *(Bos taurus* x African Sanga), initial live weight (LW; mean ± sem) 222 ± 3.8 kg, sequentially grazed five, 1 ha pastures containing predominantly (> 80 %) Rhodes grass (*Chloris gayana*) with some (< 10 %) Urochloa (*U. mosambiensis*) and *Macroptilium* spp. between 27 August and 14 September, and 27 October and 16 November 2009 (total five grazing periods of 7 to10 d). Each pasture was managed by irrigation, application of urea (150 kg/ha) and mowing to ensure similar phenological state at the time of grazing during field measurements. Adjacent areas were similarly managed to provide forage containing similar proportions of *C. gayana*, *Urochloa* sp. and *Macroptilium* spp. which was harvested for determination of diet digestibility. The movement of steers between pastures was determined by estimated group intake based on individual LW and available forage biomass so that feed availability did not compromise grazing behaviour or animal distribution within each paddock. Mean grazing DM intake was initially estimated by measuring pasture availability (kg DM/ha) before and after each of the five grazing periods. However, as the trial progressed it became apparent that intakes could not be accurately determined by this method and was subsequently estimated using the relationship between digested energy intake and LW gain, following assumptions of ARC (1980). Each steer was fitted with an archival GPS device recording spatial data at 1 to 4 Hz for each grazing period.

In a subsequent study 35 Brahman steers, mean ± sem LW of 435 ± 4.4 kg, continuously grazed a 27 ha established mixed sward consisting of (~18 %) *C.gayana*, (~16 %) *Urochloa mosambiensis* and (~15 %) *Bothriochloa* sp. with some Black speargrass (*Heteropogon contortus*) and (<15 %) introduced tropical grasses from 02 to 17 October 2011. estimated available biomass, using a modified BOTANAL technique (Tothill *et al*., 1992), was 4310 kg DM/ha.

3.2.2 *Lansdown Research Station, Queensland*

Forty eight beef steers; 15 Brahman (*B. indicus*) and 33 Belmont Red *(Bos taurus* x African Sanga), mean ± sem LW of 237 ± 3.0 kg, continuously grazed a 5.5 ha established mixed sward of (~67%) Sabi grass (*Urochloa mosambiensis*), (~18%) *Siratro* sp., (~10%) *Stylosanthes* sp. with some Blue pea (*Clitoria turnatea*), and Green panic (*P. maximum*) between 24 September and 06 October 2010. Estimated available biomass was 9413 kg DM/ha.

3.2.3 Douglas Daly Research Farm, Northern Territory

Sixty nine Brahman and Brahman cross cows, mean ± sem LW of 400 ± 7.6 kg, grazed a 100 ha improved pasture containing (~48 %) Buffel Grass (*Cenchrus ciliaris*), (~35 %) Sabi grass (*Urochloa mosambiensis*) and (~14 %) Wynn Cassia (*Chamaecrista rotundifolia)* from 22 October to 12 November 2010. Estimated available biomass was 5052 kg DM/ha.

3.2.4 Kidman Springs Research Station, Northern Territory

Seventy six Brahman x Senepol cross heifers, mean ± sem LW of 317 ± 4.5 kg, continuously grazed a 5.0 km^2 native pasture consisting of open woodland of *Bauhinia* sp. with an understorey of Native couch (*Brachyachne* convergens), Golden Beardgrass (*Chrysopogon fallax*) and occasional Mitchell grass (*Astrebla* sp.) patch. Estimated available biomass was 3005 kg DM/ha.

3.2.5 Calorimetry measurements of methane emissions from cattle fed diets containing tropical legumes

In the experiments reported by Kennedy and Charmley (2012), methane production was measured by open-circuit gas exchange for 24 h periods from 13 Brahman cattle offered 22 diets from combinations of five tropical grass species and five legumes (Table A1), with a minimum of three steers per diet. These animals were continually housed under controlled animal house conditions in individual pens. All diets were offered daily *ad libitum*, with the exception of three legume diets fed without grass and Leucaena (*Leucaena leucocephala*) mixed with grass, which were offered at 15 g DM per kg LW. Diets were fed as long-chopped dried hay, with the exception of Leucaena, which was harvested fresh from Belmont Research Station and fed within 2 days of collection after being stored in a commercial cold room. (Table A 1).

Table 1. Study site descriptors for pasture and animals for CH_4 measurement campaigns in Queensland and Northern Territory.

Site	Pasture			Animals		
	Size (ha)	Dominant species	Available biomass (kg DM/ha)	*n*	Liveweight (kg)[§]	Stocking rate (AE/ha)[ll]
Belmont Research Station*	1.0	*C. gayana*	6998[‡]	*18*	222 ± 3.8	8.9
Belmont Research Station[†]	27.0	*C. gayana*, *U. mosambiensis*	4310	*35*	435 ± 4.4	1.2
Lansdown Research Station	5.5	*U. mosambiensis, Siratro sp.*	9413	*48*	237 ± 3.0	4.6
Douglas Daly Research Farm	100	*C. cliiaris, U. mosambiensis*	5025	*69*	400 ± 7.6	0.6
Kidman Springs Research Station	500	*B. convergens, C. fallax*	3005	*76*	317 ± 4.5	0.1

[*]2009 trial, [†]2010 trial, [‡]Mean of five 1ha trial paddocks, [§]mean ± sem, [ll] AE Adult equivalent ~ 450kg steer

3.3 3.3 Methane measurements and data processing

3.3.1. Methane measurements using open-path lasers; validation study

For the initial study at Belmont Research Station (2009) methane emissions were measured for each grazing period (total 5 grazing periods of 7-10 d) using an open-path laser (OPL, GasFinder2.0, Boreal Laser Inc., Spruce Grove, AB, Canada) mounted on a digital scanning unit (PTU D300, Directed Perceptions Inc., Burlingame, CA, USA) that was remotely controlled using commercial software (GasFinder/scanner, Boreal laser Inc.). In brief, the CH_4 mixing ratio was measured daily and recorded by the laser/scanner unit along 5 paths; 2 parallel to pasture boundaries and 3 diagonally across the pasture, at a height of 1.8 m and at 22.5° intervals as described by McGinn *et al.,* (2011) to define point source dispersion within 1 ha paddocks. The scanner/laser automatically moved and aligned with a retro-reflector that terminated each path. Recording interval for line-averaged CH_4 mixing ratio (ppmv) for each path was every second for 55 s. Mean methane emissions, estimated using an indirect open-path spectroscopic / bLS dispersion model were then compared to mean 24 h emission values obtained using two open-circuit respiration chambers from individual animals when fed freshly cut forage from representative pastures (Tomkins *et al*., 2011).

3.3.2. Methane measurements using open-path lasers; field scale studies

Methane emissions from each group of cattle at each of the four field sites was measured for 4 - 5 h per day for up to 28 d using open-path lasers (Fig 1a, 1b). Recording interval for line-averaged CH_4 mixing ratio (ppmv) for all paths was every second for 55 s. Animals were confined to an area (Table A2), defined around the only water point in the study paddock, post morning grazing. This confinement assumes uniform distribution within the area and surface-source assumptions are used in a bLS dispersion model to derive methane flux. The surrounding area at each site was flat and considered to present no major obstacles to wind.

In three of the four campaigns, two OPL were used to measure line averaged methane mixing ratio for each path; one set upwind to measure the background methane mixing ratio and another mounted on a scanner measured line averaged methane mixing ratios from the source area along two perpendicular paths (Figs 2, 3, 4).

Fig. 1a Animals involved in methane flux measurements at each study site were confined at a water point after morning grazing for up to five hours.

Fig. 1b Line averaged methane flux was determined using OPL at all sites.

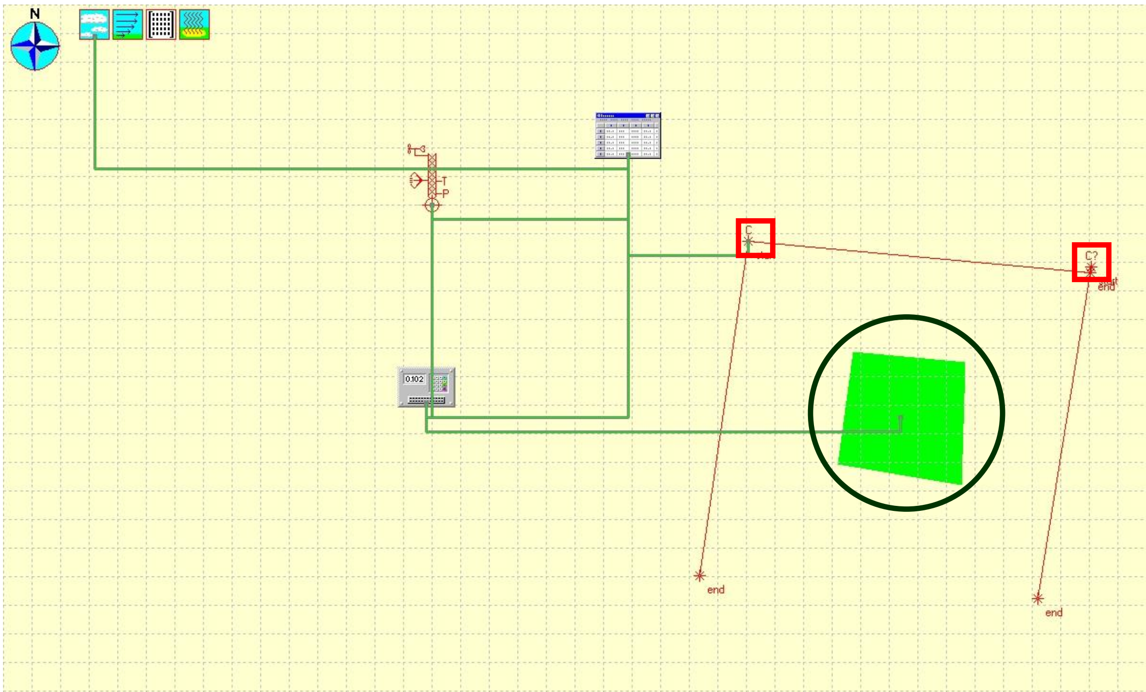

Fig. 2 WindTrax map for Lansdown Research Station campaign indicating the arrangement of OPLs (□) measuring line averaged methane mixing ratio; upwind to measure the background methane mixing ratio and downwind from the source area (○).

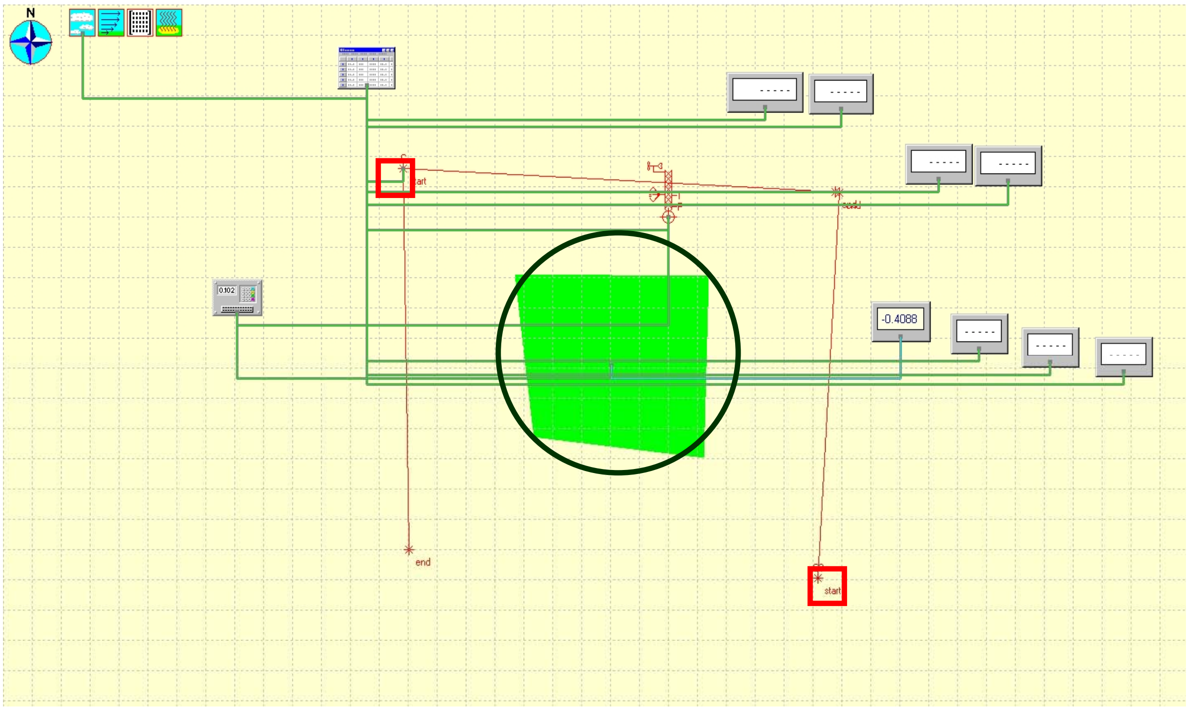

Fig. 3 WindTrax map for Douglas Daly Research Farm campaign indicating the arrangement of OPLs (□) to measure line averaged methane mixing ratio; upwind to measure the background methane mixing ratio and downwind from the source area (○).

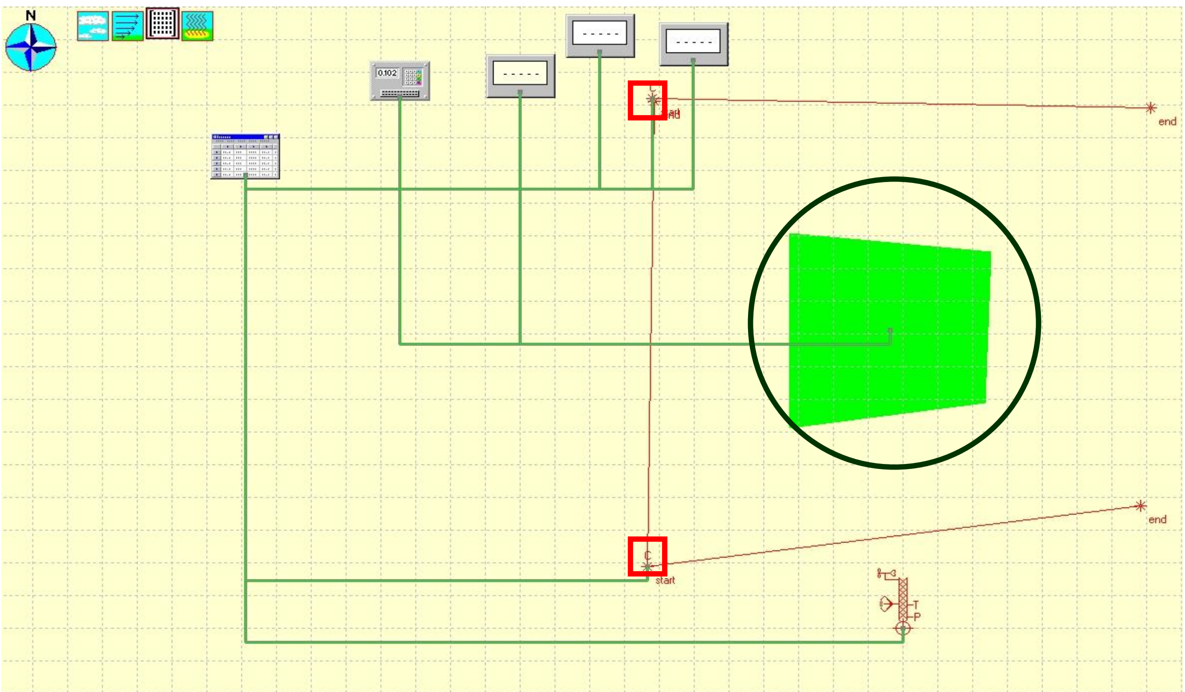

Fig. 4 WindTrax map for Kidman Springs Research Station campaign indicating the arrangement of OPLs (□) measuring line averaged methane mixing ratio; upwind to

measure the background methane mixing ratio and downwind from the source area (○).

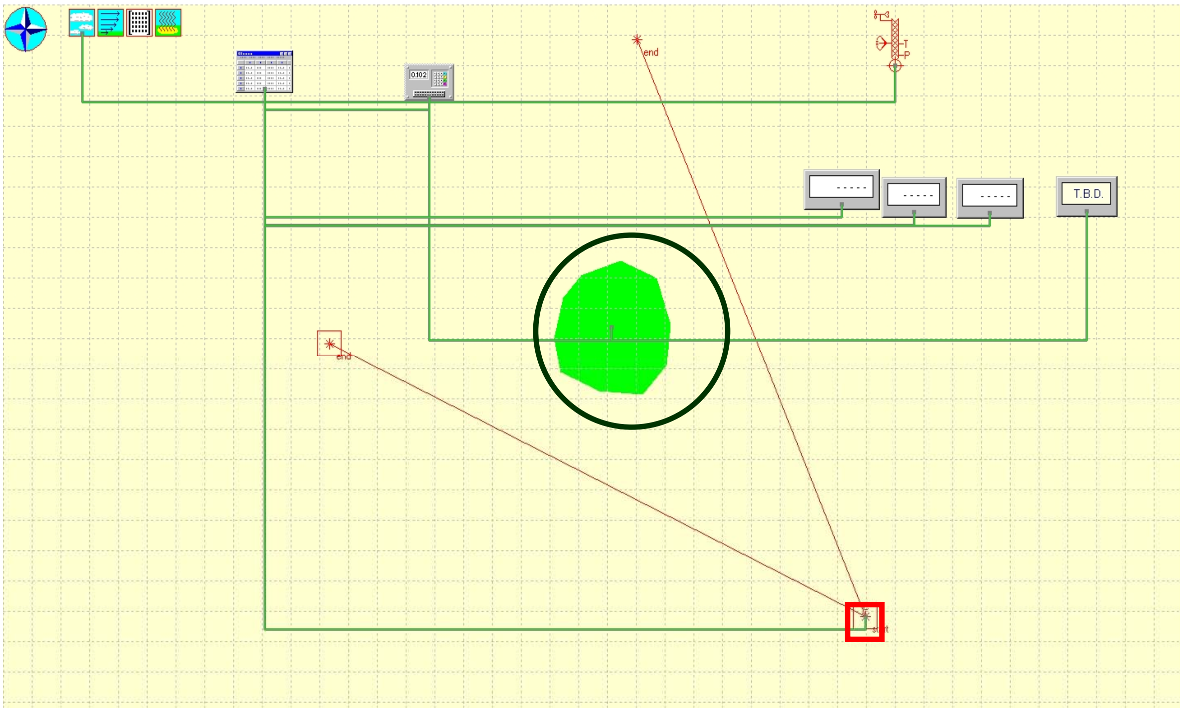

Fig. 5 WindTrax map for Belmont Research Station (2011) campaign indicating the arrangement of an OPL (□) measuring line averaged methane mixing ratio; upwind to measure the background methane mixing ratio and downwind from the source area (○).

The physical arrangement of equipment at each site was determined by historical meteorological data for wind direction to ensure that paths were predominantly measuring background or enhanced methane flux relative to each source area. A retro reflector was used to terminate each laser beam over path lengths ranging from 59 to 144 m (Table A2). Path lengths unique to each measurement campaign were used in bLS modelling to estimate emission values.

For the final campaign, at Belmont Research Station in October 2011, only one OPL was available. This laser was mounted on a scanner and measured line averaged background methane mixing ratio and methane mixing ratios from the source area along two paths ± 19.2° relative to a centre line between the scanner and centre of the source area (Fig 5).

Before and after each campaign, with the absence of animals, the CH_4 mixing ratio was recorded for each OPL unit operating along independent, but parallel laser paths. This

allowed for evaluation of systematic errors between the two units during each measurement periods.
Methane mixing ratios from each laser for each campaign was averaged over 10 min periods. Laser return light levels were also checked throughout each campaign to ensure values between 3000 and 11,000 (no units). This range is recommended by the laser manufacturer and associated CH_4 concentration readings can be considered reliable.

At each site a micrometeorological mast was located upwind and adjacent to each source area. The mast was fitted with a three-dimensional sonic anemometer (CSAT3, Campbell Scientific Inc, Logan, UT, USA) mounted at a height of 2.4 m which sampled wind components at 10 Hz. A barometric pressure sensor (CS106, PTB 110, Campbell Scientific Inc.) and temperature humidity sensors (HMP45C, Campbell Scientific Inc.), a cup anemometer and wind sentry were also mounted on the mast (Fig 6). Micrometeorological data including wind speed, direction and wind component variance were recorded at 10 Hz, averaged over 10 min intervals using a datalogger (CR1000, Campbell Scientific Inc.) and extracted daily onto a laptop computer.

3.3.2. Data processing

Laser, sonic anemometer and micrometeorological data were merged and managed with SAS (1999) statistical software as described by Tomkins *et al.,* (2011) before using bLS modelling in WindTrax (WindTrax dispersion model V.2.0.8.3,Thunder Beach Scientific, Halifax, NS, Canada). The placement of source boundaries and sensors are also required in this model. McGinn *et al*., (2010) describe data processing where animals are fitted with GPS devices to determine point-source dispersion.

The filtering criteria used throughout the studies for pre- and post-simulation (using WindTrax) were similar to that described by Flesch *et al.,* (2007) and McGinn *et al*., (2009) and included; 3000 < light level <11000, surface roughness (Z; m) 0.0000001 < Z_0< 0.9, atmospheric stability (L; m), absolute <2, friction velocity (u*; m/s) >0.15 m/s, where < 0.15 indicates calm conditions and unsteady wind directions, and fraction covered by touchdown (FRAC) > 10 % with Δ CH_4 > 10 ppb. In addition, if the wind direction relative to either open path varied by more than 15° then this data was considered unreliable and excluded from modelling using WindTrax. The CH_4 mixing ratio for each path was converted to an absolute concentration based on air pressure and temperature. Mean animal methane emission values were then calculated (g hd/d) for each study site based on the total number of 10 min average data that satisfied the filtering criterion as described.

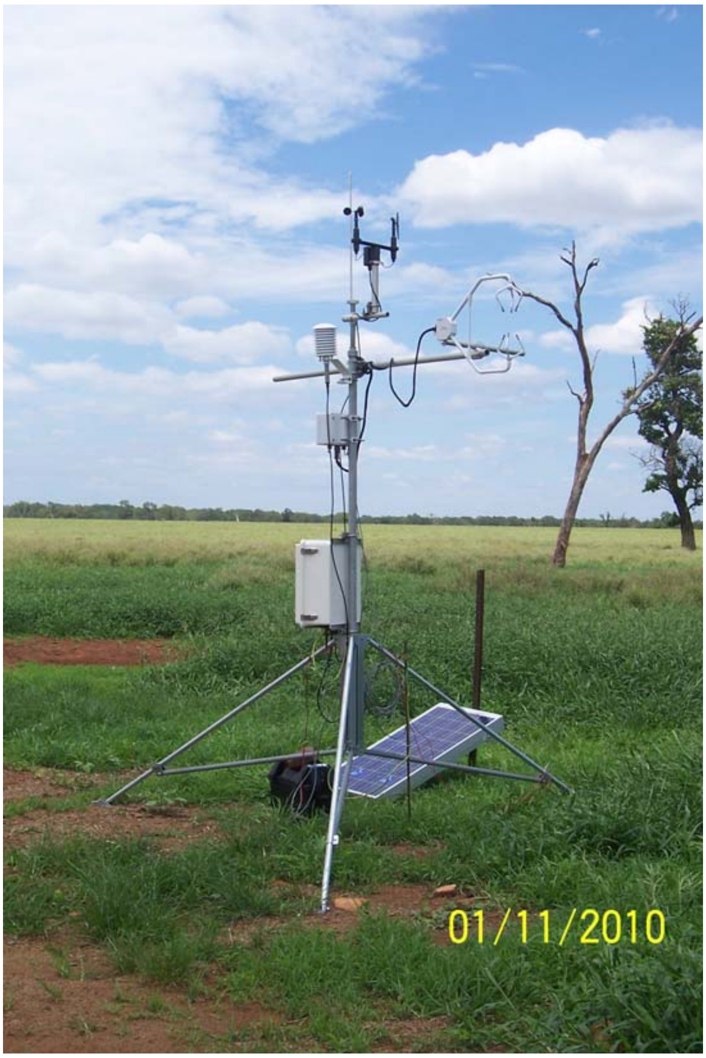

Fig. 6 At each site a micrometeorological mast equipped with a three-dimensional sonic anemometer, cup anemometer, wind sentry and temperature/humidity sensors was located upwind and adjacent to each source area

4. Results

3.4 4.1 Calorimetry measurements of methane emissions from *Bos indicus* cattle fed diets containing tropical legume species

In the experiments reported by Kennedy and Charmley (2012), methane production was measured by open-circuit gas exchange from 13 Brahman cattle offered 22 diets from combinations of five tropical grass species and five legumes, with a minimum of three steers per diet. Results indicated that methane production could be predicted as 19.6 g/kg forage dry matter intake (Table 2). Mean methane emission rates across all diets were equivalent to 8.6–13.4 % of digestible energy intake, and 5.2–7.2 % of gross energy intake. The latter values are comparable to IPCC (2006) recommendations (5.5 – 7.5 %) for large ruminants fed low-quality crop residues and by-products. Methane yields per unit of ingested DM or digested organic matter were variable across diets, but were related to digestibility and contents of fibre and protein.

These results constitute a significant downward revision of the methane emissions attributable to the northern Australian beef herd grazing tropical pastures.

3.5 4.2 Validation of open-path laser technique against calorimetry (open-circuit respiration chambers)

The comparison between open-circuit respiration chambers and an open-path spectroscopic method for determining methane emissions from beef cattle grazing a tropical pasture has been reported by Tomkins *et al*., (2011). The CH_4 emissions determined using the dispersion method were 136.1 ± 21.5 g/d or 29.7 ± 3.70 g/kg DM intake compared with 114 ± 5.1 g/d or 30.1 ± 2.19 g/kg DM intake using open-circuit respiration chambers. Patterns of 24 h CH_4 emissions derived from 10 min emission data over all days and pastures using an open-path spectroscopic / bLS dispersion model indicated that emissions were highest pre-dawn, evening and mid-afternoon, but also had large errors ranging from ± 21.7 to ± 51.7 g/d (Fig 7). Estimates of CH_4 emissions based on predictive algorithms for beef cattle grazing similar pastures range from 82.7 ± 3.98 g/d to 112.7 ± 2.57 g/d (Table 3).

Table 2 Mean methane production and yield per intake of dry matter (DMI), digested organic matter (DOMI), digested energy (DEI) and gross energy (GEI) for Brahman steers fed diets comprising grass/legume mixtures. Values are least square means (spear grass-based diets) or means with standard errors of means (sem) (Kennedy and Charmley 2012).

	Methane				
Diet*	(g/day)	(g/kg DMI)	(g/kg DOMI)	(J/J DEI)	(J/J GEI)
Spear grass L_1 +					
20% dolichos	62.2	17.9	40.0	0.123	0.055

sem	*4.44*	*1.13*	*2.89*	*0.0082*	*0.0033*
Spear grass L_2 +					
20% dolichos	67.9	19.6	42.0	0.130	0.060
40% dolichos	84.9	20.7	42.1	0.125	0.063
sem	*4.05*	*1.07*	*2.80*	*0.0077*	*0.0032*
Rhodes grass +					
22% leucaena	99.6	19.4	33.2	0.100	0.062
44% leucaena	90.6	17.8	29.5	0.086	0.054
sem	*3.72*	*0.43*	*1.20*	*0.0044*	*0.0021*
Rhodes grass +					
20% Burgundy bean	108	19.2	35.2	0.110	0.061
40% Burgundy bean	112	17.6	33.5	0.105	0.056
sem	*7.6*	*0.90*	*1.67*	*0.0054*	*0.0031*
Rhodes grass +					
20% stylo	141	20.7	38.9	0.122	0.064
40% stylo	128	21.2	41.5	0.130	0.065
sem	*10.5*	*0.60*	*1.18*	*0.0039*	*0.0018*

*Descriptors H, M, L; categories of feeding level (multiple of maintenance energy requirement, calculated according to Charmley *et al.* (2008)) where H >1.5; M > 1, < 1.5; L < 1.

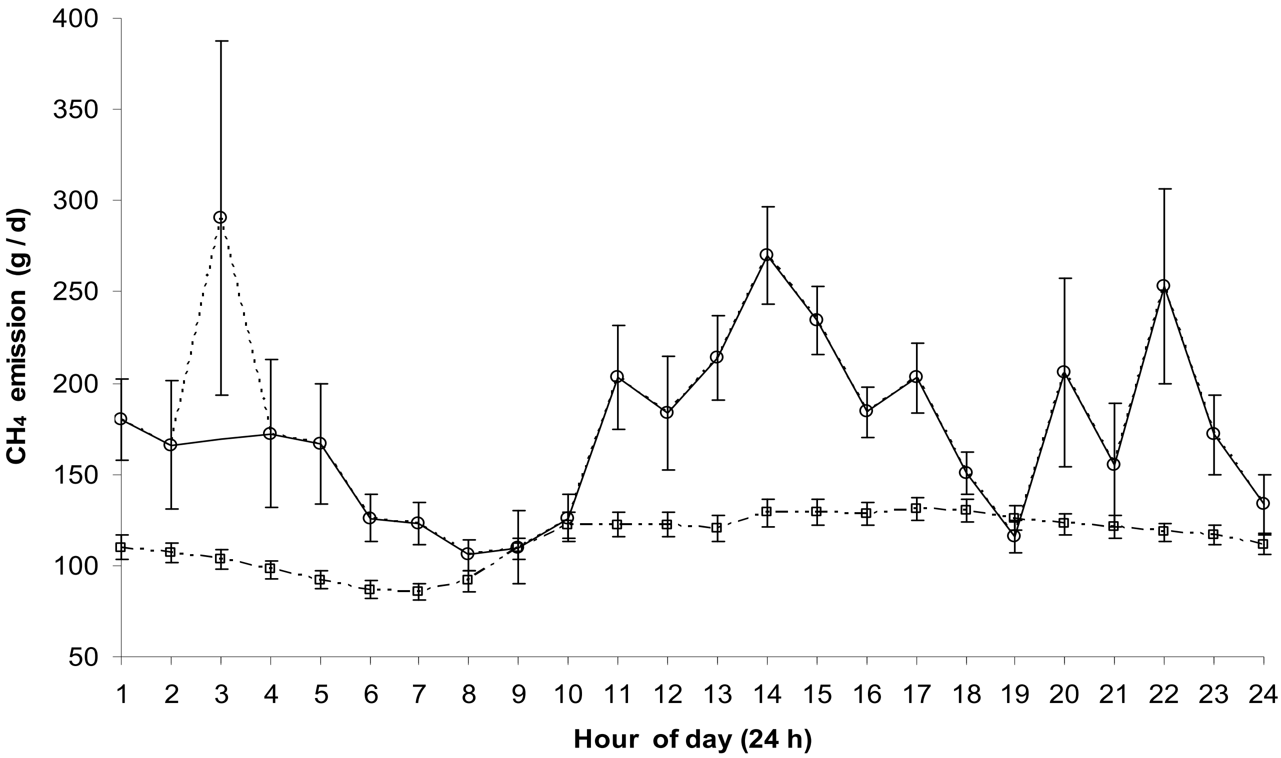

Fig. 7 Mean (± SEM) methane emissions (g/d) for steers grazing Rhodes grass pastures and estimated using an indirect open-path spectroscopic / bLS dispersion model methodology (○), or fed freshly cut material from representative pastures and measured using open-circuit respiration chambers (□). The value at 0300 is a suspected outlier.

3.6 4.3 The *in-vitro* effect of legume content in the diet on changes in methane emissions

The evaluation of tropical legumes for anti-methanogenic properties using *in-vitro* total gas production systems is on-going and in collaboration with the University of Western Australia. Collection of plant material for assessment is continuous and to date includes samples from the Atherton Tablelands, Lansdown, Douglas Daly Research Farm species sites and the living herbarium established at James Cook University, Townsville.

Specific results will be reported in milestone reports as part of B.CCH.1012, Antimethanogenic bioactivity of Australian plants for grazing systems.

Table 3. Dry matter intakes and CH_4 emissions (mean ± SM) using a dispersion method and open-circuit respiration chambers compared with predicted total methane emissions for cattle grazing or fed long-chopped Rhodes grass (*C. gayana*).

	Dispersion model *†	Open-circuit respiration chambers‡
DM intake		
kg/d	4.7 ± 0.05	4.0 ± 0.19
g/kg LW	20.0 ± 0.08	17.2 ± 0.84
Methane as measured		
g/d	136.1 ± 21.5	114.3 ± 5.12
g/kg DM intake	29.7 ± 3.70	30.1 ± 2.19
g/kg LW	0.57 ± 0.067	0.49 ± 0.022
% GE intake	9.1 ± 1.13	9.2 ± 0.71
Methane predicted (g/d) §		
Ellis *et al*., 2007	112.7 ± 2.57	
Kurihara *et al*., 1999	109.1 ± 6.74	
Yan *et al*., 2009	105.6 ± 4.78	
Charmley *et al*., 2008	100.2 ± 1.14	
IPCC., 2006	82.7 ± 3.98	

* Intake estimates for grazing periods based on ARC (1980), †Micrometeorological technique with dispersion model as described, ‡ confinement in open-circuit respiration chambers for 24 h. §These values based on calorimetry/ respiration chamber trials.

3.7 4.4 Field (commercial) scale evaluation of laser and sensor methodology measurement technology for northern production systems

Methane emission estimates for 246 cattle including steers, cows and heifers grazing northern pastures at four sites across central and northern Queensland and the Northern Territory have been conducted for a total of 98 days using an indirect open-path spectroscopic / bLS dispersion model.

The amount of valid data used to estimate CH_4 emissions at the herd scale was 56 % of the total possible data collected (Total number of 10-min averages for each campaign). The pre-filtering criteria primarily contributed to invalid data which was not used as an input to the WindTrax model. In addition, negative and outlier values of emission data (output) from the WindTrax model were removed from calculating absolute emission values. Despite the filtering criteria used, differences between days for mean methane emissions, based on valid ten minute averages for that day, were apparent for each site (Figs 8, 9, 10, 11).

Daily mean (± sem) CH_4 emissions from the five sites ranged from 136 ± 21.5 g/hd/d for steers grazing an irrigated Rhodes grass pasture to 281 ± 22.3 g/hd/d for Brahman cows grazing a *Cenchrus ciliaris* and *Urochloa mosambiensis* pasture (Table 4). The lowest emissions were associated with young steers grazing an irrigated and improved pasture fertilised with urea (150 kg/ha) and managed intensively to ensure similar phenological state across measurement periods. In comparison, the higher CH_4 emissions were associated with mature Brahman cows and heavier steers (LW> 200 kg) grazing either Buffel or Sabi grass dominated pastures, respectively.

High daily CH_4 emission values were generally observed within the first three hours of measurement. This initial measurement period appears to capture the expected increase in emissions following a feeding event which is consistent with trends observed using open-circuit respiration chambers when animals receive their daily ration once per day (Fig 7) and are confined for a measurement period. For the remainder of each daily measurement period across all sites emissions tended to gradually decline or remain constant (Fig 12).

The relationship between mean LW and methane emissions for all sites is shown in Fig 13. The relationship is similar to that described by Yan *et al.,* (2009) as indicated, but appears to under estimate emissions for a similar weight range.

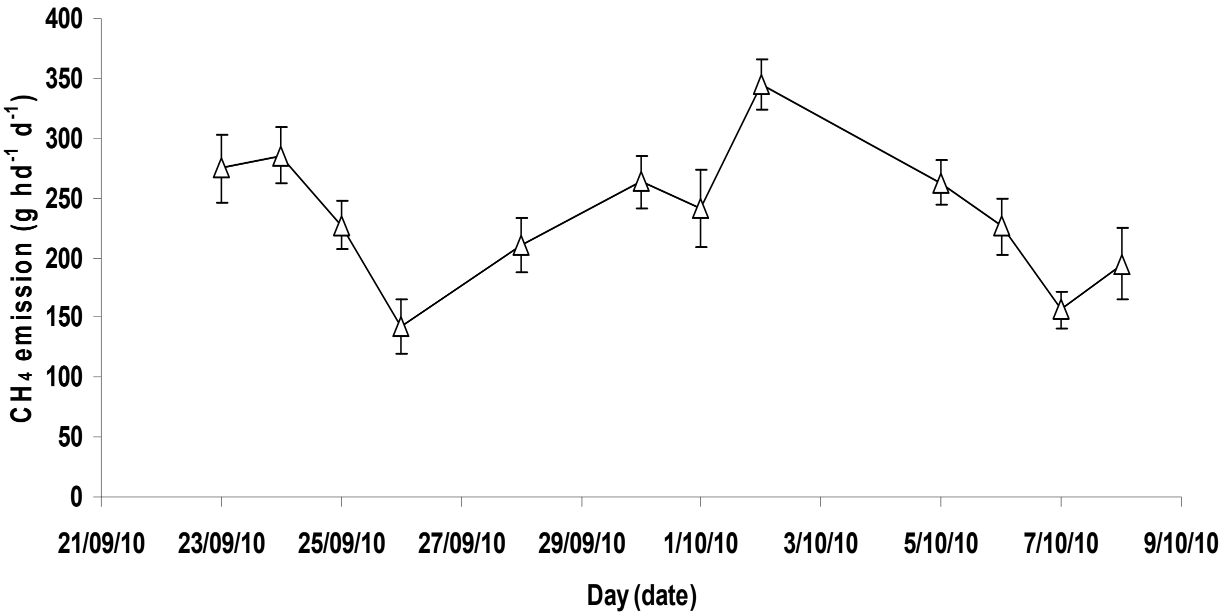

Fig. 8 Mean (± sem) methane emissions calculated on a daily basis for steers grazing *Urochloa mosambiensis* and *Stylosanthes* sp. dominated pasture at Lansdown Research Station.

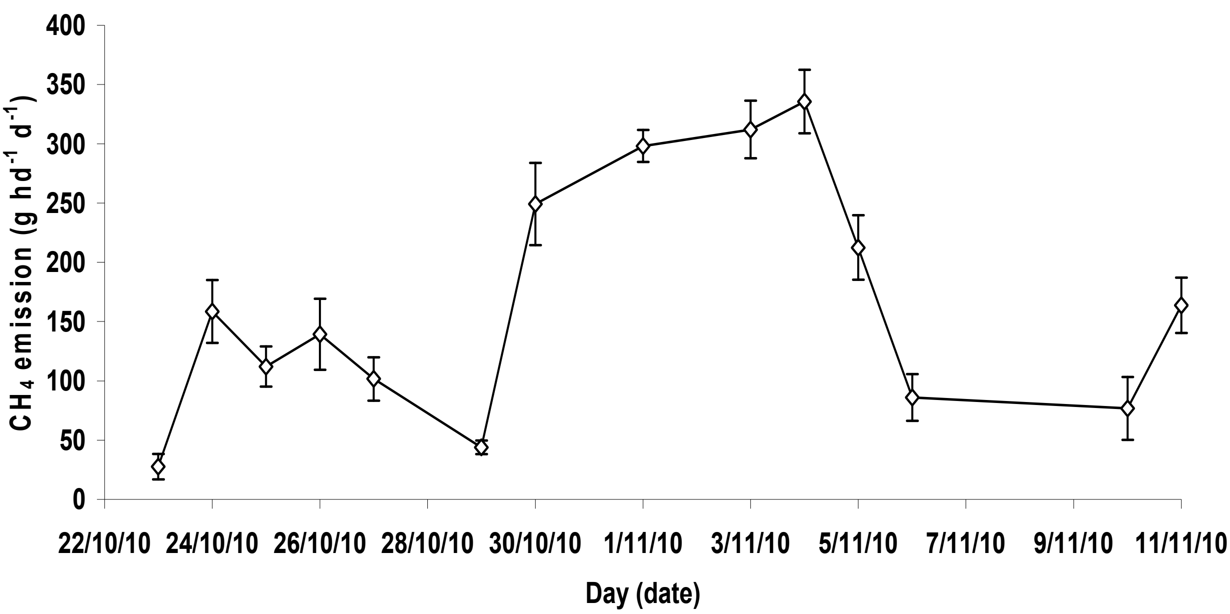

Fig. 9 Mean (± sem) methane emissions calculated on a daily basis for cows grazing *C. ciliaris, Urochloa mosambiensis* and *Chamaecrista rotundifolia* mixed pasture at Douglas Daly Research Farm.

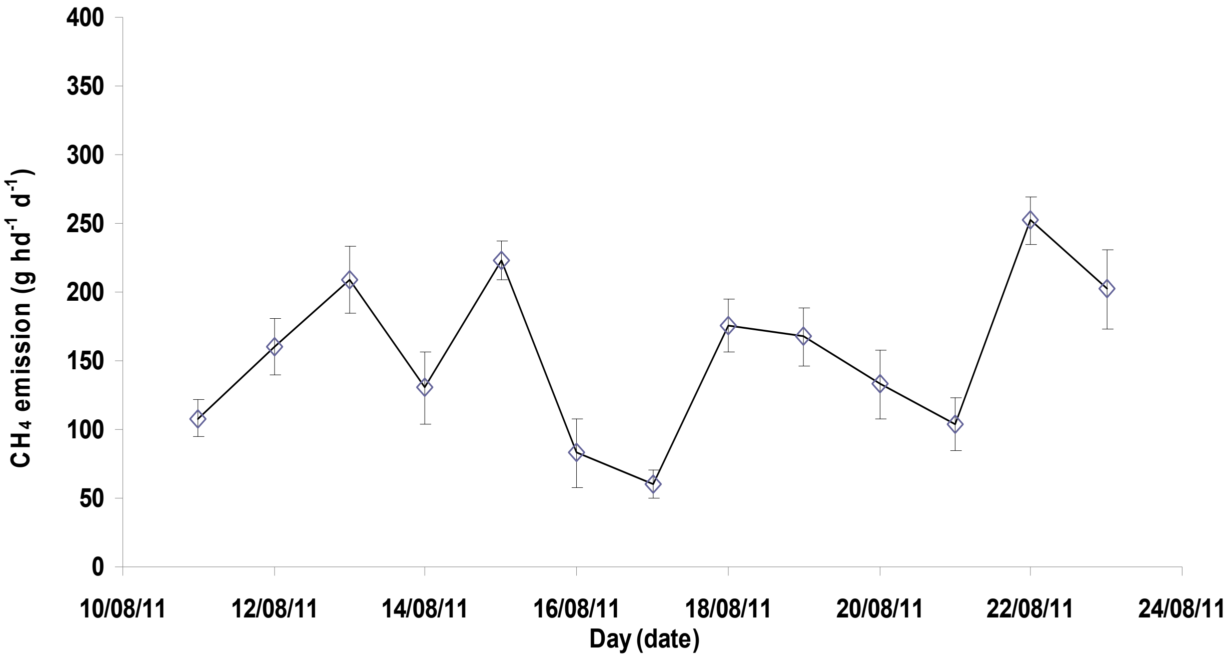

Fig. 10 Mean (± sem) methane emissions calculated on a daily basis for heifers grazing a *Brachyachne* sp. and *Chrysopogon sp.* dominated pasture at Kidman Springs Research Station.

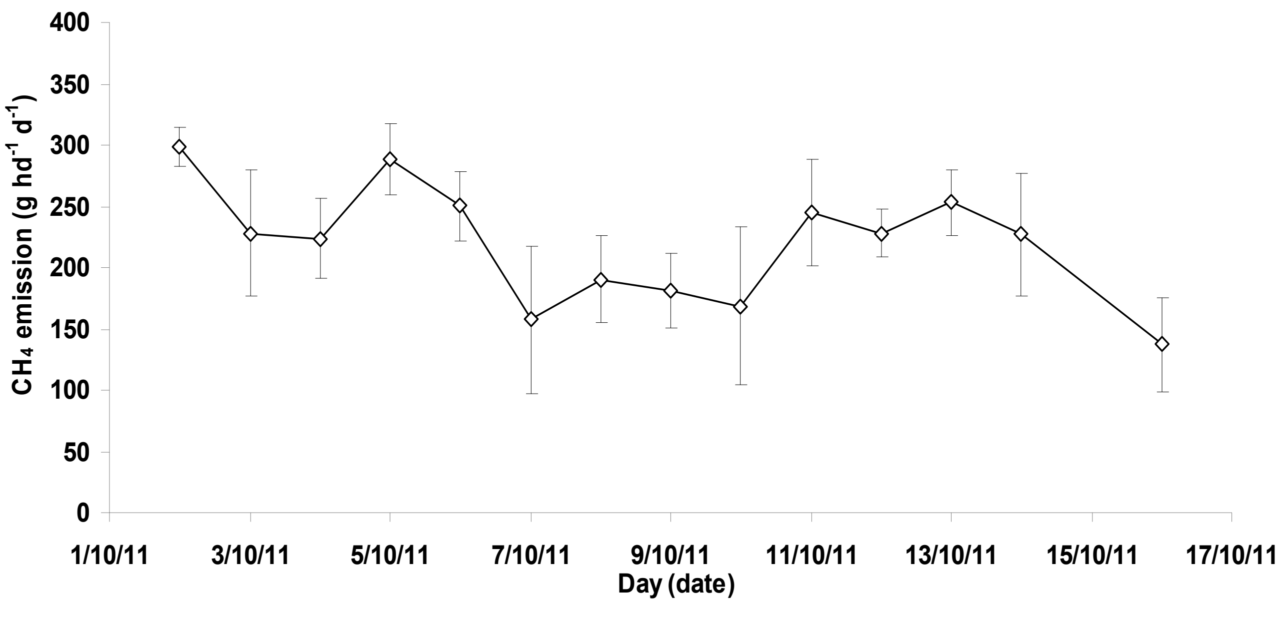

Fig. 11 Mean (± sem) methane emissions calculated on a daily basis for steers grazing a *Chloris* sp. and *Urochloa* sp. dominated pasture at Belmont Research Station (2011).

Table 4. Study dates, days of data collection, livestock class and methane emissions (mean ± sem) for five field campaigns using an OPL and bLS modelling methodology

				Methane emissions	
	Start-finish (dates)	Data Collected (d)*	Livestock measured	g/hd/d[†]	g/kg LW[‡]
Belmont Research Station[§]	27 Aug – 16 Nov	38 (20)	Steers	136 ± 21.5	0.6
Belmont Research Station[ǁ]	02 Oct- 17 Oct	16 (14)	Steers	231 ±16.6	0.5
Lansdown Research Station	23 Sept – 08 Oct	14 (12)	Steers	226 ± 7.5	0.9
Douglas Daly Research Farm	21 Oct – 12 Nov	17 (5)	Cows	212 ± 8.9	0.7
Kidman Springs Research Station	10 Aug -23 Aug	13 (12)	Heifers	162 ± 4.3	0.5

*Number of days used in bLS dispersion model to derive mean methane emissions. Values in parenthesis are actual days used to report emission data, †extrapolation based on 4-5h measurements, ‡CH_4 emission/mean live weight (LW; kg), §2009 with individual animals modelled as point source, ‖2011 with animals confined and surface source assumptions.

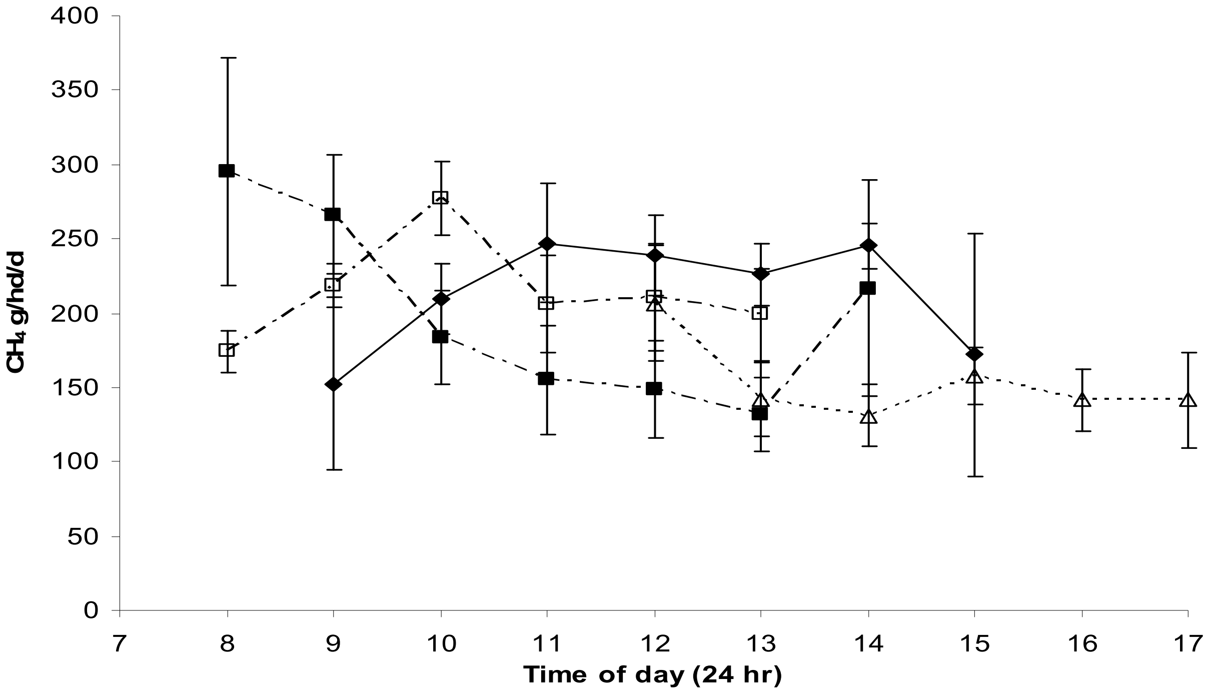

Fig. 12 Mean (± sem) hourly methane emissions from cattle confined at water over 5 to14, 5h periods for the study sites; Belmont Research Station 2011 (steers) ◊, Douglas Daly Research Farm (cows) ■, Lansdown Research Farm (steers) □ and Kidman Springs Research Station (heifers) Δ. Measurement periods not consistent between days. Hourly emission values based on 10 min average data for that hour equivalent to g/head/d.

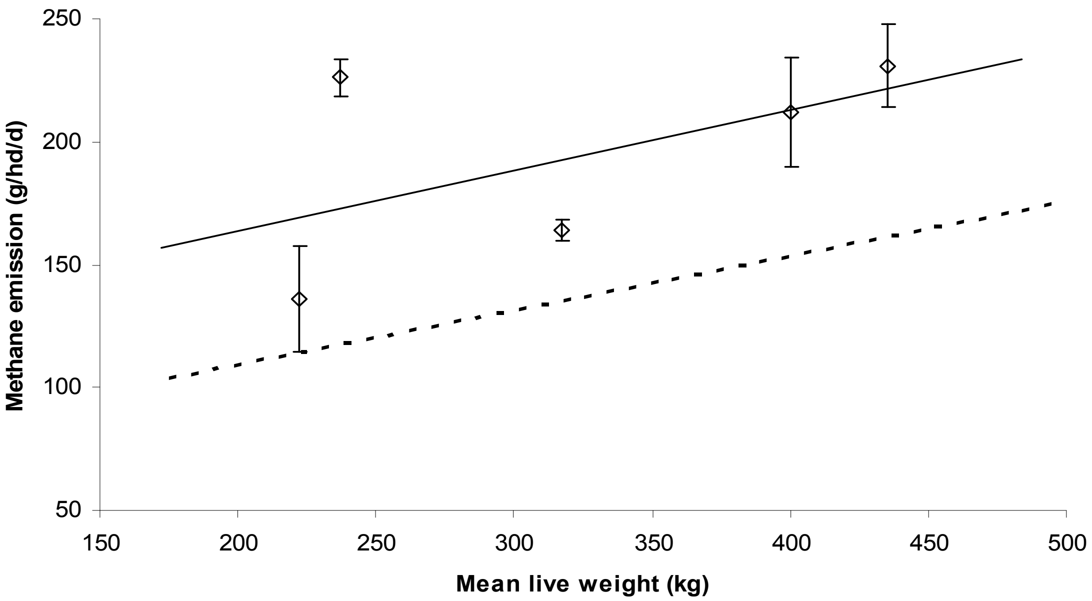

Fig. 13 Relationship between live weight (LW) and total mean (± sem) methane emission (◊) for five sites using OPL methodology (CH_4 (g/hd/d) = 0.24(LW)+115.1, R^2=0.31). Additional line (---) indicates relationship described by Yan *et al*., (2009).

4 5. Discussion & conclusion

This study was the first of its kind and reports five measurement campaigns conducted on properties across Queensland and Northern Territory using an indirect open-path spectroscopic / bLS dispersion method to estimate methane emissions from beef cattle grazing native and improved pastures.

The pastures available for this study ranged from irrigated and fertilised Rhodes grass to predominantly *Brachyachne* sp. and *Chrysopogon* sp. dominated swards. Nutritional factors including level of intake and digestibility are known to influence methane production in cattle (Johnson and Johnson, 1995) and to date have been the basis for predicting methane emissions for ruminant livestock (Blaxter and Clapperton 1965). Nevertheless, feeding conditions used to generate predictive equations usually involve diets fed at restricted levels of intake, ranging from one to three times maintenance energy requirements compared to feeding conditions in northern Australia where available forage is consumed *ad libitum*. Obtaining sufficient data sets on animal intake and digestibility for extensive grazing environments can be challenging. In this study pasture composition and quality estimates were generated using Faecal NIRS (F.NIRS), but will be reported separately.

Daily mean (± sem) CH_4 emissions measured using the indirect open-path spectroscopic /bLS methodology across all pastures and livestock ranged from 136 ± 21.5 g/hd/d to 281 ± 22.3 g/hd/d. These emissions were influenced by diet and livestock at each site. The lowest emissions were associated with young steers grazing an irrigated and improved pasture fertilised with urea (150 kg/ha) and managed intensively to ensure similar phenological state. In comparison, the higher CH_4 emissions were associated with mature Brahman cows and heavier steers (LW> 200 kg) grazing either *Cenchrus ciliaris* or *Urochloa mosambiensis* dominated pastures, respectively. The results confirm that methane emissions in grazing systems across northern Australia can be benchmarked using the indirect open-path spectroscopic / bLS dispersion method. This methodology has previously been used to estimate trace gas emissions from feedlots (Loh *et al*., 2008; McGinn *et al*., 2008) and has also been validated against open-circuit respiration chambers (Tomkins *et al*., 2011) as part of this study.

The results reported by Laubach *et al*., (2008) also indicate that the dispersion methodology is equally applicable to extensive grazing situations for herd scale measurements, although estimates can be higher than those obtained using alternative methods such as the SF_6 tracer technique.

This project has not been able to obtain measurements from only one livestock class to obtain any direct comparison between sites or investigate seasonal effects at any one site. The measurements obtained in the study are unique to each site and dependent on the weather conditions at the time of measurements. Methane emissions were within the range of values previously suggested for steers grazing improved and native pastures (Hunter 2007 and McCrabb *et al.*, 1997), although generally higher than the values reported by Kennedy and Charmley (2012) for hay diets based on grasses typical of major beef-production regions of Queensland fed to steers under animal house conditions. Daily mean emissions measured using the indirect open-path spectroscopic / bLS dispersion method at Douglas Daly Research Farm for Brahman cows were lower than the values previously suggested for mature Brahman cows (Charmley *et al*., 2008) although generally greater than those reported for Brahman steers (107 to 159 g CH_4/d) fed Buffel grass hay harvested at three different levels of maturity (Kennedy and Charmley, 2012). These emissions may be related to differences in animal LW; Kennedy and Charmley (2012) used Brahman steers (mean ± sem LW; 227 ± 6.2 kg) compared with Brahman cows (mean ± sem LW; 400 ± 7.6 kg) used in this study. Charmley *et al*., (2008) model emissions based on Brahman cows with a mean age over 6 years and make allowances for gestation and lactation, but do not define actual liveweight used in the metabolisable energy component of the NABCEMS model. Emission values similar to current IPCC Tier I emission factors (IPCC 2006) were limited to Brahman cross heifers grazing predominantly *Brachyachne* sp. and *Chrysopogon* sp. dominated pastures indicating that current values used for national inventory purposes are only representative of a small portion of the northern beef herd.

Daily mean methane emission data (g/hd/d) for each campaign has been presented to indicate the variation between days. Differences between days were most obvious for the Douglas Daly campaign where methane flux and micrometeorological data was collected over a total of 17 days, but only five of those days were used to generate actual emission data (g CH_4 /hd/d). The filtering criteria used pre-processing in this study and others (McGinn *et al*., 2008, 2009) is intended to remove invalid data that would otherwise generate unreliable values using the Windtrax model. Data presented for the Douglas Daly campaign clearly indicated that satisfying filtering criteria alone would not necessarily generate biologically valid methane data for ruminant livestock. Only five days of emission data was eventually considered representative of the animals used in this campaign. Predictive algorithms based on LW (Yan *et al*., 2009) suggest that these animals could have produced approximately 154 g CH_4/d. A similar relationship described in this study generates a value closer to 211 g CH_4/d and a value as high as 453 g CH_4/d is suggested for similar animals supplemented with molasses (Charmley *et al.,* 2008). The addition of energy digestibility and ME/GE to support LW with feeding level, DM intake and GE intake have been shown to increase the predictive accuracy of equations to estimate CH_4 emissions of beef cattle (Yan *et al*., 2009). However, the intent of this study was to apply an indirect open-path spectroscopic / bLS dispersion method to acquire emission data directly from cattle managed in a commercial environment where measuring addition variables such as feeding level, DM intake or digestibility is not possible. The indirect open-path spectroscopic / bLS dispersion model methodology is reliant on wind turbulence data sets that can change within and between days. This will contribute to the variation in emission estimates between days reported in the current study for each site and is particularly obvious for the Douglas Daly and Kidman Springs campaigns.

The relationship between animal LW and methane production for the animals used in this study is similar to that previously reported; LW is generally considered a poor predictor of CH_4 production in beef cattle when compared with DM intake and GE intake, (Yan *et al.,* 2009), but to date has been the only non invasive alternative to estimate emissions for distinct herds across northern Australia. Direct measures of emissions obtained using the indirect open-path spectroscopic / bLS dispersion method also indicate differences between each study site which reflect the variation in production systems in terms of pastures and class of livestock. Diet quality effects on the individual animal and herd structure reflecting management and marketing decisions have previously been identified as drivers of livestock production and methane emissions at the property and regional levels (Charmley *et al*., 2008). The measurement methodology therefore provides an opportunity to evaluate regional variation in baseline methane emissions for extensively managed livestock in northern Australia and assess property mitigation practices that may be included in the Carbon Farming Initiative (CFI; DAFF 2011).

This report was to also include a proof of concept for a potential reduction in methane emissions from northern Australian beef cattle systems. Reductions in total methane emissions, expressed as kg/calf of up to 11% over a period of six years have been reported (Charmley *et al.,* 2008), but are dependent on increased levels of supplementation and herd fertility. This scenario is also associated with increases in daily methane emissions, but principally illustrates the relative importance of simply targeting reductions in methane emissions compared with accounting for the impact of reduced methane emissions on overall energy balance of the animal. Larger reductions of up to 31% over 25 years have also been suggested (Bentley *et al.,* 2008), but are expressed on a t CH_4/t LW weaned basis and are essentially based on a complete change of herd structure. This study was not conducted to assess emission reductions on each site although data collected in the field using the indirect open-path spectroscopic/bLS dispersion method could populate a methane model to investigate mitigation outcomes. Conducting additional measures on the same herds to identify emission rates before and after the implementation of any mitigation strategy would be required to quantify any effective reduction in CH_4 emissions for a defined production system.

On farm practices aimed at methane mitigation are more likely to target emission intensities (t GHG/t liveweight gain, or kg GHG/kg beef yield) rather than daily emissions reported in this study. Nevertheless, investment to raise efficiency of cattle production by improving herd genetics, property infrastructure and utilisation of the seasonal feed-base can be expected to reduce the number of unproductive animals, reduce age-at-slaughter (Bentley *et al.,* 2008) and inevitably reduce emissions from the livestock sector in northern Australia.

In addition to validating the indirect open-path spectroscopic / bLS dispersion method for extensive livestock systems a number of sensors have also been suggested as viable options for determining indirect measures of enteric methane production for grazing cattle. To date, progress in developing sensors as proxies has been delayed and no additional work has been conducted since September 2010.

5 6. Impact on the Livestock Industry

By its nature this project was not intended to have an immediate direct impact on the livestock industry. The use of an indirect open-path spectroscopic / bLS dispersion methodology to better understand and eventually predict GHG emissions in heterogeneous grazing environments has been assessed under experimental and commercial conditions. Nevertheless, the ability to generate baseline emission data unique to production systems, bioregions or individual herds will be invaluable to the industry as a whole when mitigation strategies are implemented and reductions can be quantified over time.

Implementing measurement methodologies that complement normal animal behaviour will be crucial in ensuring a low input strategy to quantify mitigation practices. Further development of equipment rather than the indirect open-path spectroscopic / bLS dispersion methodology is required to have this technology more widely adopted by the industry. Developing a system that interfaces with current technology such as electronic identification systems (EIDs) to identify individual animals and source intensity (number of animals measured) will be beneficial and support long term measurements.

Additional studies with different tropical pastures and herds are required to obtain estimated CH_4 emission values for further comparisons with predictions from the Australian GHG Inventory and those currently reported in the literature for beef cattle.

6 7. Appendices

6.1 7.1 Financial report

End of month financial reporting is currently not available. Whole of project financial report will now include March 2012, but will not be available until 06 April 2012.

6.2 7.2 Summary report, Feedback/Frontier article, Web Abstract, draft and published scientific papers

Summary Report

Methane (CH_4) emissions from cattle grazing pastures characteristic of northern Australia are yet to be reliably quantified. Poor quality pastures, marked seasonal rainfall and low animal productivity are characteristic of northern Australia, but are also associated with high CH_4 emissions intensity/unit animal product. A number of methodologies are available to measure individual emissions; respiration chambers, SF_6 (sulphur hexafluoride) tracer technique, or have been suggested; blood methane concentrations, whole body thermography, but are difficult to use other than at an individual animal level and not applicable to estimating emissions for extensive grazing environments. The smallest unit of measure to characterise livestock greenhouse gas emissions may be at the herd scale. There are no suitable methods for measuring emissions for the northern beef herd, yet measurement is a critical component in mitigation and a carbon farming framework. This project was conducted to address this deficiency.

This report details the validation and application of a methodology for estimating CH_4 emissions at the herd scale using open-path lasers with micrometeorological data and a dispersion model. Unique data sets have been collected for production systems in Queensland and the Northern Territory for a total of 98 days involving 246 cattle including steers, cows and heifers. In addition, methane production from 13 Brahman steers, maintained under animal house conditions, offered 22 diets from combinations of five tropical grass species and five legumes, with a minimum of three steers per diet, has been measured using open-circuit respiration chambers.

Daily CH_4 emissions associated with five sites ranged from 136 g/hd/d for steers grazing an irrigated Rhodes grass pasture to 281 g/hd/d for Brahman cows grazing a Buffel/ Sabi grass pastures. The lowest emissions were associated with young steers grazing an irrigated and fertilised pasture. In comparison, the higher CH_4 emissions were associated with mature Brahman cows and heavier steers (LW> 200 kg) grazing either Buffel or Sabi grass dominated pastures. Methane emissions were within the range of values previously suggested for steers grazing improved and native pastures (Hunter 2007 and McCrabb *et al.*, 1997), although generally higher than the values reported by Kennedy and Charmley (2012) for diets including Spear grass and Buffel grass hay fed to steers under animal house conditions. Emission values, determined using open-path lasers, similar to current IPCC (2006) Tier I emission factors were limited to Brahman cross heifers grazing predominantly Native couch and Golden Beardgrass pastures. This suggests that current values used for national inventory purposes are only representative of a small portion of the northern beef herd. Emissions at the farm scale will vary depending on pasture type, seasonality and class of ruminant livestock, making the usefulness of herd scale emission data invaluable for national inventories, when a large number of properties can be captured in a series of measurement campaigns.

Feedback/Frontier articles/other

Less hot air in northern herd. In *Farm Weekly* 19 Jun, 2011

CSIRO discovers there's more moo than phew. In *Farm Weekly* 14 Jul, 2011

Feedback TV Episode 15 October 2011. Cutting emissions: boosting production

Web abstract

Methane (CH_4) emissions associated with beef production systems in northern Australia are yet to be quantified. Methodologies are available to measure individual emissions, but application in extensive grazing environments is difficult.

A methodology for estimating herd scale emissions using open-path lasers and a dispersion model is described. Data sets have been generated from properties in Queensland and Northern Territory. In addition, 22 diets, combining tropical grass and legume species, have been fed to cattle under animal house conditions and CH_4 emissions measured using open-circuit respiration chambers.

Daily mean (± sem) CH_4 emissions from the study sites ranged from 136 ± 21.5 g/hd/d to 281 ± 22.3 g/hd/d. Low emissions were associated with young steers grazing irrigated and fertilised Rhodes grass. High emissions were associated with mature Brahman cows and heavier steers grazing Buffel/Sabi grass pasture. Animal house studies indicated that CH_4 production could be predicted as 19.6 g/kg forage dry matter intake. Mean CH_4 emission rates across all diets were ~ 5.2 – 7.2 % of gross energy intake which compare favourably with IPCC (2006) for large ruminants fed low-quality crop residues and by-products. Methane emission values for mixed diets have been characterised and can be benchmarked in grazing systems across northern Australia using the indirect open-path spectroscopic / bLS dispersion method.

Draft and published scientific papers

Kennedy, P.M. and Charmley, E. 2012. Methane yields from Brahman cattle fed tropical grasses and legumes. *Anim. Prod. Sci*. In press; *http://dx.doi.org/10.1071/AN11103*

McGinn, S.M., Turner, D., Tomkins, N.W., Charmley, E. and Chen, D. 2011. Methane emissions from grazing cattle using point-source dispersion. *J. Environ. Qual*. **40**, 22-27.

Tomkins, N.W., McGinn, S.M., Turner, D.A. and Charmley, E. 2011. Comparison of open-circuit respiration chambers with a micrometeorological method for determining methane emissions from beef cattle grazing a tropical pasture. *Anim. Feed Sci. Tech*. **166-167**, 240-247.

Tomkins, N.W., Bai, M., Turner, D.A. and Charmley, E. 2012. Beef cattle methane emissions across northern Australia using an indirect micrometeorological - dispersion method. In draft

6.3 7.3 Supporting data from draft and published scientific papers

Forage	Description*
Black speargrass (*Heteropogon contortus)*	Low quality hay, harvested from the Belmont Research Station, 34% leaf.
Black speargrass (*Heteropogon contortus)*	Very low quality hay harvested from Belmont Research Station, 33% leaf
Buffel grass *(Cenchrus ciliaris)*	Medium quality hay harvested from Belmont Research Station, 61% leaf.
Buffel grass *(Cenchrus ciliaris)*	Medium/high quality hay harvested from Belmont Research Station, 60% leaf.
Buffel grass *(Cenchrus ciliaris)*	High quality hay harvested from Belmont Research Station, 70% leaf.
Bisset creeping bluegrass cv Bisset (*Bothriochloa insculpta*)	Medium quality hay harvested from Brian Pastures Research Station, 41% leaf.
Bisset creeping bluegrass cv Bisset (*Bothriochloa insculpta*)	Medium quality hay harvested from Brian Pastures Research Station, 26% leaf.
Mitchell grass (mixture of *Astrebla lappacea, Astrebla elymoides)*	Mixture of 2 medium quality hays harvested near Longreach, Qld, 38% leaf.
Rhodes grass cv Callide (*Chloris gayana)*	Medium quality hay harvested at Belmont Research Station, 38% leaf.
Dolichos (*Dolichos lablab)*	Large leaved legume, determined to be 98% legume, harvested as hay at Belmont Research Station, 57% leaf.
Burgundy bean (*Macroptilium bracteatum)*	A twining a trailing perennial with large leaves, determined to be 70% legume. Harvested as hay from Belmont Research Station, 78% leaf.
Stylo cv Verano (*Stylosanthes hamata)*	A perennial with narrow elongate leaves, determined to be 96% legume. Harvested as hay post seed production from the Atherton Tableland, Qld, 34% leaf.
Leucaena cv Cunningham (*Leucaena leucocephala*)	A low-tannin variety of a perennial browse legume. Leaves and small twigs harvested fresh form the Belmont Research Station, 69% leaf. Fed within 2 days of harvest.
Lucerne (*Medicago sativa)*	Commercially purchased hay

*Belmont Research Station (23.21° S; 150.39° E) and Brian Pastures Research Station (25.40° S, 151.45° E) located in Queensland.

Table A1. Characteristics of the forages used in calorimetry measurements of methane emissions from cattle fed diets containing tropical legumes (Kennedy and Charmley 2012)

Table A2 Animal number per site, indicating source strength, source area size, path length, mean wind speed, direction and temperature at five study sites.

	Belmont Research Station*	Belmont Research Station†	Lansdown Research Station	Douglas Daly Research Farm	Kidman Springs Research Station
Animal (n)	18	35	48	69	76
Confinement area (m^2)	10000	347.2	430.0	897.8	759.0
Source intensity (m^2/animal)	555	10	9	13	10
Path length (m)					
Path 1	107.8	103.4	59.1	63.0	71.1
Path 2	120.2	103.2	60.2	74.8	71.4
Path 3	143.5	_	_	_	_
Path 4	108.7	_	_	_	_
Path 5	94.1	_	_	_	_
Background	94.8	_	58.7	63.9	71.6
Leading wind direction	NE	NE to SW	ENE	ESE	ESE
Wind speed (m/s)					
minimum	0	0.1	0.1	0.1	0.7
maximum	5.0	7.8	4.5	7.6	5.7
Temperature (°C)					
minimum	7.8	5.2	18.4	22.8	5.6
maximum	34.8	34.9	33.2	39.0	37.9

*2009 trial using GPS devices with animals grazing 1 ha paddocks, †2010 trial

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