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A longitudinal study of methane emissions by cattle grazing buffel grass or buffel grass–*Desmanthus* pastures

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ABSTRACT

Context. Reducing methane emissions from grazing cattle is important to reduce the environmental impact of Australia's beef industry. **Aim.** A 16-month grazing study was completed on a commercial property in central Queensland, to determine the animal production and methane emission response to including *Desmanthus* in buffel grass (*Cenchrus ciliaris*) pastures. **Methods.** There were two treatments (Control (~95% buffel grass) and *Desmanthus* (~70% buffel grass/30% *Desmanthus*). A group of 400 tropical composite yearling heifers was divided according to liveweight (LW) to four 300 ha paddocks. Of these, 98 self-selected to for in-field methane monitoring units throughout the study. Pastures were evaluated for biomass and botanical composition, and cattle were weighed and sampled for faeces every 2–4 months. Pasture and faecal samples were analysed for nutritive value by near-infrared analysis. Spatial variation in pasture and animal activity was observed using global positioning system (GPS) technology. The data were analysed as a 2 × 3 factorial, with two treatments assessed over three seasons, namely, wet season 1 (15 December 2023 to 16 April 2024), dry season (16 April 2024 to 9 October 2024) and wet season 2 (9 October 2024 to 30 April 2025). **Key results.** Overall, *Desmanthus* tended to increase LW gain and increased hot half-carcase weight. When season was included in the analysis, there were treatment by season interactions for LW gain, and methane production (g/head.day), yield (g/kg DM intake) and intensity (g/kg LW). In wet seasons, *Desmanthus* increased LW gain and reduced methane yield (g/kg DM intake), and intensity (g/kg LW) by 8% and 9% respectively, whereas in the dry season, there was no treatment effect. There was a treatment by season interaction for diet nutritive value and the percentage of non-grass (predominantly *Desmanthus*). **Conclusion.** The response in animal performance and methane emissions was due to the presence of *Desmanthus* in the diet of cattle in the wet seasons. **Implications.** The inclusion of legumes such as *Desmanthus* in tropical pastures is an available option to reduce methane emissions from grazing cattle.

Keywords: buffel grass, cattle, *Desmanthus*, greenfeed, legume, methane, pasture, tropical.

Introduction

In Australia, 95% of methane emissions from cattle and sheep are predicted to be derived from grazing livestock (Meat and Livestock Australia 2020). It is therefore important to understand how emissions are influenced by season and pasture type. Methane production from pasture species typical of those used in northern Australia has been measured most frequently by harvesting material as hay or fresh material and feeding under controlled conditions where methane production and yield can be measured with open-circuit respiration chambers (Kennedy and Charmley 2012; Perry *et al.* 2017; Suybeng *et al.* 2020, 2021; Stifkens *et al.* 2022). A meta-analysis of data from forage diets in northern Australia suggested that the methane yield form tropical forage diets was 20.6 g/kg DM, and was not different from the overall value of 20.7 g/kg DM, the value used to estimate methane emissions for all Australian cattle fed 70% plus forage diets (Charmley *et al.* 2016). Although measuring methane under controlled conditions is useful to obtain the definitive relationship between a known forage and the resultant methane production, it is a poor representation of the pasture–animal interface under grazing conditions. Until recently, pasture-based measurements of methane emissions from cattle have been obtained using open-path laser (McGinn *et al.* 2011) or sulfur hexafluoride (SF_6) techniques (Chaves *et al.* 2006). Both techniques present challenges, particularly under extensive grazing conditions in northern Australia. Measurements over more than days (SF_6) or weeks (laser) are difficult to obtain because of animal welfare (SF_6) or environmental limitations (laser). Additionally, the laser technique can measure emissions only on a herd basis (McGinn *et al.* 2011). Tomkins *et al.* (2011) compared methane production from either grazed tropical pasture using the open-path laser method or the same pasture cut and carried daily to cattle in respiration chambers. Methane emissions from both methods were dissimilar, being 0.57 and 0.49 g/kg liveweight (LW) for the laser and chamber methods respectively. Tomkins and Charmley (2015) used open-path lasers to measure herd emissions from grazing cattle on several properties across northern Australia and demonstrated a range in methane production of between 0.40 and 0.63 g/kg LW. Sakamoto *et al.* (2020) used the SF6 technique to compare methane production by cattle grazing tropical forages across a range of pasture types and management scenarios and obtained values of between 0.3 and 0.6 g/kg LW. These data suggest that methane emissions on pasture vary widely and may be considerably higher than are values from respiration chamber studies. Within the past decade, the gas emissions monitoring (GEM) system has become widely adopted in Australia, offering the ability to measure individual emissions from cattle on a daily basis for long periods of time. Additionally, it provides results that accord with respiration chamber data (Hammond *et al.* 2016).

In northern Australia, pastures are typically dominated by C4 grasses of seasonally variable and low nutritive value. The inclusion of tropically adapted legumes is becoming an increasingly more common practice to increase the nutritive value of the pasture and, consequently, the performance of grazing livestock. Tropical legumes have been shown to inhibit methane production *in vitro* (Durmic *et al.* 2017) and *in vivo* by using respiration chambers (Suybeng *et al.* 2020; Stifkens *et al.* 2022). The presence of bioactive compounds including tannins, as well as alterations to rumen fermentation through the introduction of a rapidly degradable N source, have both been implicated in reducing methanogenesis (Meat and Livestock Australia 2015). In addition, the inclusion of a legume in the diet frequently increases feed intake and animal performance, leading to a reduction in methane intensity as methane production per unit of animal output (Harrison *et al.* 2015). There is a lack of information on the effect of legumes to reduce methane in grazing cattle under field conditions. Chaves *et al.* (2006) showed that alfalfa increased methane intensity, and MacAdam *et al.* (2022) found that birdsfoot trefoil and cicer milk vetch reduced methane intensity relative to temperate grass pastures. Both studies used short-duration SF_6 measurements. Meat and Livestock Australia (2015) reported on a study with growing cattle grazing Rhodes grass or Rhodes grass–leucaena pastures. Open-path lasers were used to measure herd methane emissions for approximately 14 day periods on four separate occasions over 2 years. Methane production varied between 130 and 280 g/day, and the inclusion of leucaena in the diet reduced methane intensity as a result of increased rates of gain and earlier turn-off. This study demonstrated that there were marked seasonal differences in methane production and that tanniferous legumes can reduce emissions when included in pastures.

The development of the C-Lock GEMs (Zimmerman and Zimmerman 2012) allows for potentially longer-term measurement of methane production from grazing livestock, although most studies employ single or sequential short-duration measurements (Waghorn *et al.* 2016; Jonker *et al.* 2020). The objective of the current study was to deploy GEMs on a 16 month grazing trial to study seasonal variation in animal performance, methane emissions and slaughter data from cattle grazing grass or grass–*Desmanthus* pastures in northern Australia under commercial conditions.

Materials and methods

The research comprised a 16-month grazing trial. The work was conducted on a commercial property in central Queensland (24°40′S, 147°09′W) between December 2023 and April 2025. The property, 'Cungelella', was owned by the Northern Australia Pastoral Company (NAPCO). The study complied with the Australian Code for the Care and Use of Animals for Scientific Purposes and was approved by the CSIRO Large Animal Ethics Committee (ARA-22/08).

Paddock design, climatic and edaphic features

The research area comprised four adjacent ~300 ha paddocks, each supplied with a single water point and a GEM unit (C-Lock Inc., Rapid City, SD, USA) located near the water point (Fig. 1). Two paddocks contained >95% buffel grass and two paddocks were a buffel grass–*Desmanthus* mixture (Fig. 1). All paddocks had been established with buffel grass >10 years before the study. The *Desmanthus* paddocks were renovated by offset disc plough in 2018. *Desmanthus* (Progardes mixture or *D. virgatus* (JCU-2, JCU-5), *D. bicornutus* (JCU-4), and *D. leptophyllus* (JCU-7)) was arial seeded following restriction of buffel grass with glyphosate (Bayer Australia, Pymble, NSW, Australia) in 2019. Buffel dieback, a condition that causes the death of pastures (State of Queensland 2017), was noted in the season prior to the study in the grass paddocks. These were burned in December 2022 to control the spread of the condition. No other treatments were applied to the paddocks. Cungelella lies within the Brigalow (*Acacia harpophylla*) bioregion. Analysis of topsoil

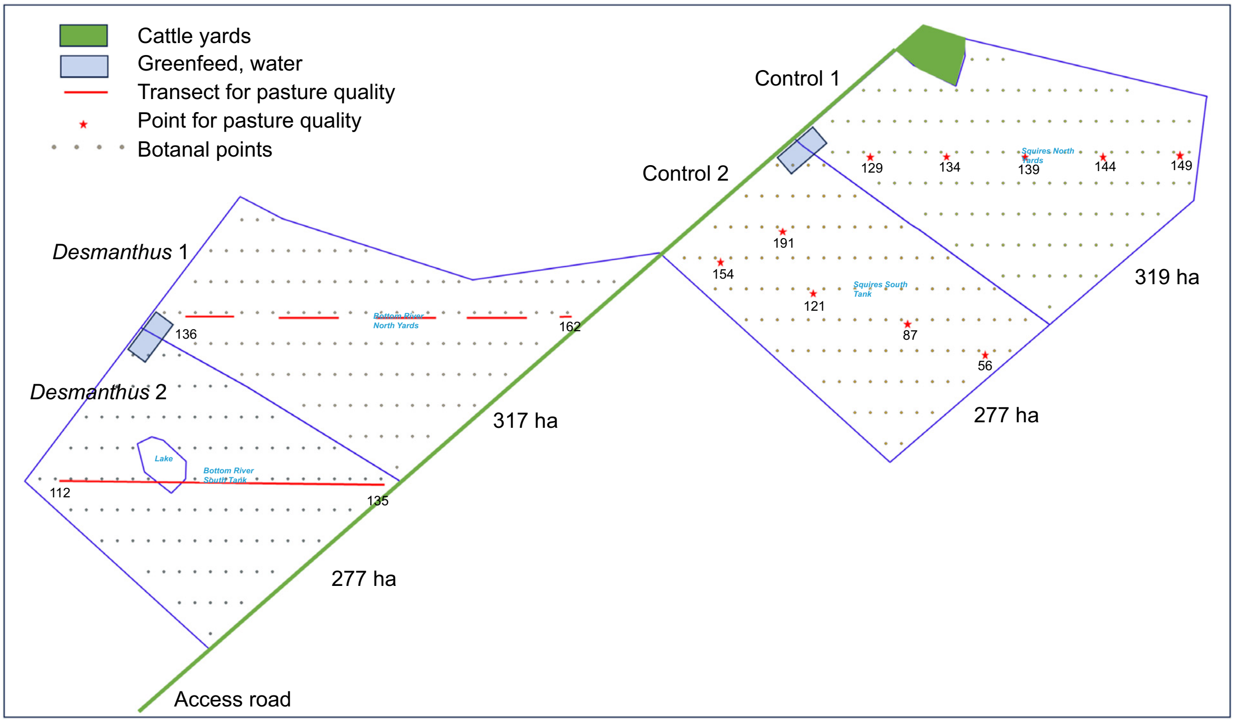

Fig. 1. Schematic of study area.

in the paddocks prior to the study showed dark brown to black-coloured soils with soil textures varying from light to heavy-textured clay soils (35–47% clay) with an alkaline pH (pH 7.3–8.4). Available phosphorus (Colwell extract) was 28 mg/kg and sulfate sulfur was 9 mg/kg. The mean annual rainfall for Cungelella is 599 mm per annum (Cungellela farm records). Rainfall immediately before and during the study was below normal, with most rain occurring between December and February of each season (Fig. 2). Minimum and maximum monthly temperature means for the area were 21.5°C and 36.3°C respectively.

Data were separated into wet and dry seasons. Using rainfall data and observed changes in the proportion of green pasture biomass, the initial wet season (Wet season 1) was classified from 15 December 2023 to 16 April 24, dates that corresponded with animal weighings. The dry season was classified from 16 April 2024 to 9 October 2024, dates again corresponding with animal weighings. The final wet season (Wet season 2) covered the period from the end of the dry season to the end of the study (9 October 2024 to 30 April 2025).

Animals and management

All cattle were from the Northern Australia Pastoral Company (NAPCO) composite breeding program, being a mixture of *Bos taurus* and *Bos indicus* genetics. Four hundred yearling heifers were selected from a group of 800 head transferred to Cungelella from Alexandria Station in the Northern Territory. They were quarantined on station for 10 days before being allocated according to LW to the four paddocks. Thirty cattle within each paddock were tagged with visual identification tags. These animals were subsequently included for faecal sampling. Of the 400 cattle allocated to the trial, data analysis for animal performance and methane emissions was restricted to 98 animals, for which there was continuous methane data throughout the 16-month study. Because cattle self-selected for methane measurements, 31, 16, 27 and 24 animals for Control replicates 1 and 2, and *Desmanthus* replicates 1 and 2 respectively, were consistently visiting GEM units throughout the measurement period. Between 74% and 83% of these were also sampled for faeces. Cattle were set stocked in their respective paddocks for the duration of the trial at an average stocking rate of ~4 ha/adult equivalent (AE). Cattle were treated for parasite control on arrival at the station and at 3 month intervals, with Moxidectin (5 g/L; Virbac (Australia) Pty Ltd, Wetherhill Park, NSW, Australia). The measurement period of the trial ended on 30 April 2025. Cattle were slaughtered on 3 June 2025, within 24 h of arrival at JBS, Dinmore, Qld, approximately 700 km from the cattle property. All cattle were slaughtered according to standard industry practice and subjected to the Meat Standards Australia (MSA) grading system (Meat and Livestock Australia 2025).

Animal sampling

Of the original 400 head, a number of animals were removed for management reasons not related to the trial and 14 heifers were pregnant and not included in the analysis. Thus, there

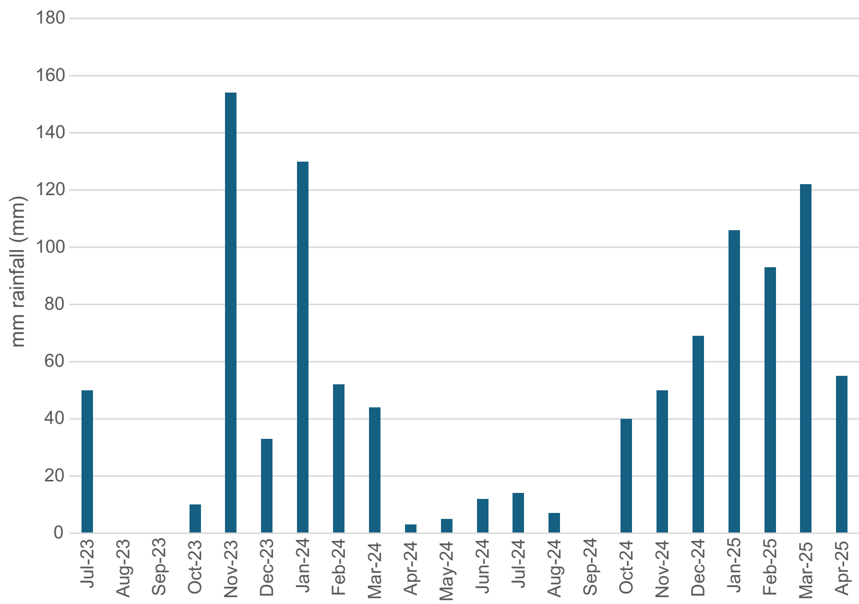

Fig. 2. Monthly rainfall totals for Mantuan Downs located within 50 km of study site.

were 90, 93, 93, and 78 animals grazing Control paddocks 1 and 2 and *Desmanthus* paddocks 1 and 2 respectively. In total, 30–35 cattle per paddock were selected according to frequency of use of GEM units on 1 February 2024 for potential methane measurement, such that the initial LW (mean ± s.d.) of selected cattle (234 ± 7.9 kg) was similar to the initial LW (mean ± s.d.) of all cattle in the paddocks (235 ± 8.7 kg). All cattle were weighed periodically throughout the trial, according to the schedule in Table 1. Weighing events were timed to coincide with critical seasonal periods, approximately equating to the wet, transition, mid-dry and late-dry seasons. Cattle were mustered by paddock and weighed at cattle yards located between 0.5 and 5 km from paddocks. To standardise shrinkage, cattle were held at the yards to ensure the duration between mustering and weighing was equalised across paddocks. At weighing, the 30 pre-selected cattle were sampled for faeces by rectal palpation. Faecal samples were frozen at −15°C within 4 h of sampling for subsequent near-infrared (NIR) analysis for dietary N, faecal N, DM digestibility and %non-grass.

Methane emissions were measured using GEM systems (C-Lock Inc., Rapid City, SD, USA), with one unit deployed adjacent to the only water source in each paddock (Fig. 1). Initially, all cattle were given access to the units with numbers periodically reduced up to 1 February 2024 when data recording was initiated. Thus, within 6 week of trial commencement, access was restricted to 30–35 head per unit, on the basis of visitation rates. Data collected during the initial 6 weeks were used to calibrate the GEM units. Methane, together with the gases CO_2, O_2 and H_2, was measured as outlined by Hammond *et al.* (2016). Briefly, the field-based units were solar powered and utilised satellite-based connectivity (StarLink Internet Services Pty, Ltd, Sydney, NSW, Australia) for communication. Breath samples were collected individually from animals identified using radio frequency identification (RFID) tags whenever they accessed the unit for a feed reward. The

Table 1. Data collection dates throughout the evaluation of the first and second cohorts of cattle.

Trial start/end date	Wet season start/end date	Cattle weighing date	Pasture sampling date (Botanal)	Faecal sampling date	Methane measurement start/end date	Collar deployment start/end date
			30/08/2023			
15/12/2023 (start)	15/12/0023 (start)	15/12/2023				
					01/02/2024 (start)	
		13/03/2024	13/03/2024	13/03/2024		13/3/2024 (start)
	16/04/2024 (end)	16/04/2024				
		06/06/2024	06/06/2024	06/06/2024		06/06/2024 (end)
	09/10/2024 (start)	09/10/2024	09/10/2024	09/10/2024		
		18/12/2024	18/12/2024	18/12/2024		
30/04/2025 (end)	30/04/2025 (end)	30/04/2025	30/04/2025	30/04/2025	30/04/2025 (end)	

feeding schedule was programmed to drop up to eight 40 g allocations of horse pellets (Barastoc Calm Performer, Ridley Agriproducts, Harristown, Qld, Australia) on up to five occasions per 24 h period, with the minimum interval between feeds >2 h. These were chosen to supply only modest amounts of nutrients and the estimated mean daily intake of crude protein (CP) and digestible energy (DE; for horses) was 58 g CP and 5.7 MJ DE (approximately 4.6 MJ/day metabolisable energy (ME)). Mean monthly methane production data were analysed on only the same set of animals consistently by using the GEMS throughout the study. This led to uneven numbers of animals per replicate, with 31, 16, 27 and 24 individuals for Control replicates 1 and 2 and *Desmanthus* replicates 1 and 2 respectively. The mean and median number of visits to GEM units were 1.57 and 1.48 visits a day respectively, with 0.07% classed as outliers (>6 visits per day) that were removed from the analysis. Methane emissions were calculated as total daily methane production per head (g/day), methane per unit dry-matter intake (DMI) (g/kg DMI), and methane per unit LW gain (LWG) (g/kg LW gain).

Animal behaviour

In March 2024, five of the selected animals per paddock were fitted with Commonwealth Scientific and Industrial Research Organisation (CSIRO) designed solar-powered collars (Arablouei *et al.* 2023; Charmley *et al.* 2024) for determination of distance travelled and spatial distribution throughout the paddocks. Details have been given in Charmley *et al.* (2024). Briefly, collars were programmed to collect the GPS position of cattle every 30 s from 13 March 2024 to 6 June 2024. Data filtering removed days where <99% of GPS fixes were obtained, the GPS accuracy was <98% and less than three satellites were used to obtain a fix. During the first 10 days of deployment, a minimum of three collars per paddock met these criteria and data from these animals were used to determine daily travel distance and location within the paddock. Animal position within the paddock over the first 10 days of deployment was determined using Q-GIS software (ver. 3.34.3; https://qgis.org/) to determine preference ratios for biomass and legume percentage by cross-referencing animal position with quantile contours for these variables (Tomkins *et al.* 2009). A value of <1 indicated avoidance, a value of >1 indicated attraction to a biomass or legume quantile. As there was low variability among animals in daily distance travelled, satisfactory filtered data from all functioning collars were used to evaluate change in travel distance over the 85-day deployment period.

Pasture measurements

Pastures were assessed for biomass and botanical composition by using the Botanal method (Tothill *et al.* 1992) at approximately 2–4 month intervals to correspond with key changes in season (Table 1). At the final sampling (30 April 2025), data were unable to be collected from the *Desmanthus* replicate 1, owing to operational problems. Data were collected with android tablets (TabActive3, Samsung, Samsung Digital City, South Korea) by using the Open Data Kit (ODK) methodology as developed by NSW Department of Primary Industries (W. Badgery, pers. comm.). There were between 115 and 125 geolocated Botanal sampling sites per replicate arranged by rows in an east–west orientation. The distance between rows was 200 m and points within a row were 100 m apart. Five points, selected to represent a cross-section of each Control replicate and twenty points in *Desmanthus* replicates, were selected for pasture sampling by cutting material at 50 mm above ground level in a 0.25 m^2 quadrat (Fig. 1). Samples were analysed for NIR analysis of N, acid detergent fibre (ADF), neutral detergent fibre (NDF), dry-matter digestibility (DMD) and hemicellulose. Replication was higher in *Desmanthus* paddocks to account for higher species variation.

Near-infrared analyses of pasture and faeces were performed as described by Coates and Dixon (2011). Details are given in Charmley *et al.* (2024). Samples were dried at 65°C in a forced-air oven and ground through a 1 mm screen by using a knife mill (Cyclotec CT293, Foss, Mulgrave, Vic, Australia) and analysed using a monochromator (Model 6500, NIRSystems, Silver Spring, MD, USA), by using a calibration database of about 1400 samples composed of tropical forages collected in Queensland, and comprising a range of mostly undefined C_3 species (Coates and Dixon 2007, 2011). Spectral scanning of pasture samples predicted N, ADF, NDF, and DM digestibility, with 10% of samples being validated against total N (Leco CN628 N analyser; Leco, St Joseph MI USA), ADF and NDF (Ankom Tech. Co., Fairport NY USA) and DMD by the pepsin cellulase method (Klein and Baker 1993) Hemicellulose was calculated as the difference between NDF and ADF. Scans of faecal samples were used to estimate the dietary content of N, DMD, and the %non-grass from an estimation of C3 plant percentage in the diet. In this study, C3 plants comprised predominantly legumes (mainly *Desmanthus*), and some herbaceous species (eucalypt regrowth).

Statistical analyses

The trial was designed as a 2 × 3 factorial with two treatments (Control and *Desmanthus*), and three seasons (Wet 1, Dry and Wet 2), with two paddock replicates per treatment. Paddock replication was included in the statistical analysis and was significant for biomass, nutritive value of the standing biomass, methane yield and methane intensity ($P < 0.05$). The statistical model can be described as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} is the observed value of the dependent variable for the kth replicate of the ith level of treatment and the jth level of season, μ is the overall mean, α_i is the main effect of treatment, β_j is the main effect of season, $(\alpha\beta)_{ij}$ is the interaction effect of treatment by season, and ε_{ijk} is the error associated with each observation. For clarity, paddock replicate means are not included in tables. Marked seasonal differences in the proportion of green material in the pastures were used to separate data into wet and dry seasons. Data collected within each season was pooled to give a mean value for season and treatment. All data were analysed using the GLM package of SAS (SAS Institute, Cary, NC, USA). Diet nutritive value was measured on up to 30 head per paddock. Mean monthly methane production data were analysed on only the same set of animals consistently by using the GEMS throughout the study. This led to uneven numbers of animals per replicate with 31, 16, 27 and 24 individuals for Control replicates 1 and 2 and *Desmanthus* replicates 1 and 2 respectively. Methane intensity of these animals was derived from methane production divided by the mean LW for the season. Methane yield (g/kg DMI) was determined from the seasonal average LW and LWG to estimate DMI (Minson and McDonald 1987). For all animal variables, the animal was the replicate within paddock. For estimation of pasture biomass, and botanical composition, the mean of datapoints within a georeferenced sampling row was used as the sampling replicate ($n = 9$ for Replicate 1, and 10 for Replicate 2). For pasture nutrient composition, the sample was the replicate ($n = 5$ for Control paddocks and 20 for *Desmanthus* paddocks). Statistical analysis of grazing behaviour and grazing preference was restricted to three animals per replicate for which complete datasets were collected over 10 days. Probability of a difference was declared when $P < 0.05$. A trend was declared when $P < 0.10$ and > 0.05.

Results

Animal performance

Tables 2 and 3 and Fig. 3 summarise the performance data for all selected cattle that remained on trial throughout the entire 16-month measurement period. Initial LW averaged 234 kg and was similar for all paddocks. Overall LWG tended to be greater for cattle in *Desmanthus* paddocks ($P = 0.053$; Table 2). Final LW averaged 550 and 565 kg for Control and *Desmanthus* treatments respectively ($P = 0.035$). At slaughter, hot half-carcase weight was greater for cattle grazing *Desmanthus* pastures than for control cattle ($P = 0.005$). There were no significant treatment differences in any other carcase measurements ($P > 0.05$). When LWG was compared within season (Table 3), it was apparent that LWG was greatest in wet season 1 (~1 kg/day), least in the dry season (~0.4 kg/day), and intermediate in wet season 2 (~0.6 kg/day), resulting in a significant season effect ($P < 0.001$) and treatment by season interaction ($P < 0.01$). Cattle grazing the *Desmanthus* paddocks exhibited greater LWG in the Wet season 1 ($P < 0.05$), but LWG was not treatment influenced in the dry or Wet season 2 ($P > 0.05$).

Table 2. Effect of *Desmanthus* inclusion in the pasture on animal performance and slaughter characteristics.

Item	Control	*Desmanthus*	s.e.	*P*
n	47	51		
Stocking rate (ha/AE)[A]	3.73	3.85		
Initial live weight (kg)	233	234	1.25	0.449
Final live weight (kg)	550	565	5.21	0.035
Live weight gain (kg)	317	332	0.045	0.053
Live weight gain (kg/day)	0.63	0.66	0.011	0.053
Hot half carcase weight (kg)	149	154	1.34	0.005
Hump Height (mm)	65.3	68.9	3.36	0.438
Eye muscle area (cm^2)	74.3	75.9	1.50	0.404
Ossification (100–590)	158	165	7.43	0.523
MSA marbling (100–1190)	380	382	10.5	0.896
Meat colour (1–9)	2.35	2.67	0.112	0.576
Fat colour (0–9)	1.57	1.73	0.201	0.554
P8 fat (mm)	25.7	24.1	1.18	0.304
Rib fat (mm)	12.7	13.0	1.061	0.808
Muscle pH	5.04	5.19	0.229	0.635
MSA index (30–80)	51.2	51.0	2.48	0.962

MSA, Meat Standards Australia.
P8 fat, a measure of fat depth taken at the rump.
[A]1 adult equivalent (AE) = 450 kg steer.

Pasture characteristics

For Botanal measurements of biomass, green material, ground cover, buffel grass and *Desmanthus*, there were significant ($P < 0.001$; Table 3) treatment effects. Seasonal differences in biomass were less, although still significant ($P < 0.011$), with mean values being greatest in Wet 1, intermediate in Dry and least in Wet 2. In the wet seasons, biomass yield and green material percentage were approximately 40% lower for the *Desmanthus* treatment ($P < 0.05$), whereas in the dry season there was no treatment effect ($P > 0.05$). Ground cover was consistently lower for *Desmanthus* paddocks in all seasons ($P < 0.05$). Buffel grass accounted for over 90% of pasture species in Control paddocks and less than 80% in *Desmanthus* paddocks ($P < 0.001$). Differences in *Desmanthus* content were apparent in each season ($P < 0.05$), varying between 16% and 29% across the three seasons. *Desmanthus* was functionally absent from Control paddocks ($P < 0.001$).

Treatment had no effect on nutritive value of pasture ($P > 0.05$), except that NDF was lower for pasture in Control paddocks ($P = 0.007$; Table 4). Marked seasonal differences were observed in nutritive value of pasture ($P < 0.001$), with lower N and DMD and higher ADF and NDF in the dry season. Hemicellulose was lower in *Desmanthus* versus Control paddocks ($P < 0.001$). There were no treatment × season interactions for any of the above variables.

Table 3. Effect of *Desmanthus* inclusion in the pasture and season on animal performance, and Botanal measurements of pasture biomass, green material, ground cover, buffel grass and *Desmanthus*.

Item	Wet 1		Dry		Wet 2		s.e.	*P*		
	Control	*Desmanthus*	Control	*Desmanthus*	Control	*Desmanthus*		T	S	T × S
Liveweight gain (kg/day)	0.90a	1.08b	0.45	0.36	0.62	0.60	0.045	0.476	<0.001	0.006
Biomass (t/ha)	7.56b	4.65a	6.16	4.84	5.57b	3.45a	0.521	<0.001	0.011	0.315
Green material (%)	55.1b	36.8a	6.65	10.9	81.9b	63.1a	2.318	<0.001	<0.001	<0.001
Ground cover (%)	73.1b	56.4a	62.0b	45.2a	71.1b	49.3a	3.163	<0.001	0.003	0.654
Buffel grass (%)	92.9b	67.8a	94.8b	79.1a	95.8b	79.3a	2.473	<0.001	0.007	0.117
Desmanthus (%)	0.39a	29.2b	0.03a	17.6b	0a	15.6b	1.913	<0.001	<0.001	0.002

Significant treatment differences within season are indicated by different lower-case letters (at $P = 0.05$). S, season; T, treatment.

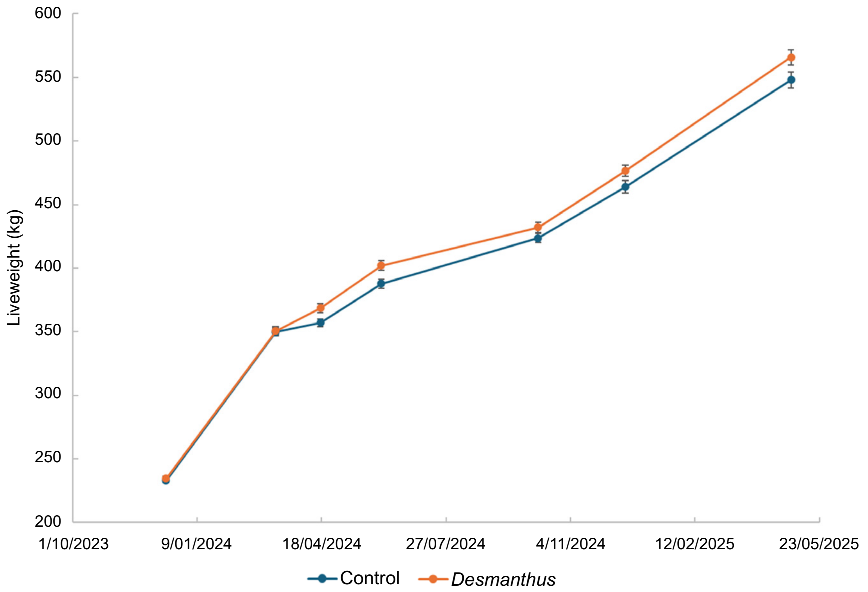

Fig. 3. Liveweight of heifers grazing Control or *Desmanthus* paddocks between December 2023 and April 2025. Data from selected cattle only.

The effects of treatment, season and their interaction were significant ($P < 0.001$) for all measured parameters of diet nutritive value as measured by NIR in faecal samples, suggesting that responses in the wet seasons were different from those in the dry season (Table 4). The nutritive value of the selected diet was typically higher than that of the pasture, with N content being approximately double and DMD was almost 30% higher (Table 4). The effect of treatment on dietary N was influenced by season, with the dietary N content in *Desmanthus* diets being higher in the dry season and lower in the wet seasons ($P < 0.01$) than that of Control diets. Faecal N content was higher for cattle grazing *Desmanthus* than for those on Control pasture ($P < 0.001$). However, this effect was apparent only in the wet seasons, when faecal N was approximately 30–50% higher for *Desmanthus* cattle ($P < 0.05$). Conversely, DMD was lower for cattle on *Desmanthus* in the wet seasons ($P < 0.05$). The percentage non-grass in the *Desmanthus* diet was markedly higher in the wet seasons ($P < 0.05$), suggesting that *Desmanthus* contributed a higher proportion of the diet in wet seasons. This difference was not apparent in the dry season, with approximately 20% of the diet on both treatments being characterised as non-grass. Because almost no *Desmanthus* was observed in Control paddocks, it is assumed that the 12% to 22% non-grass recorded in faecal samples from Control cattle was attributed to other C_3 species, such as other legumes and eucalypt browse.

Spatial variation in biomass, *Desmanthus* and cattle

Fig. 4*a* shows the variation in biomass across the four paddocks in the first wet season (March 2024). For Control paddocks, biomass was uniform across the area, with the exception of an area in Replicate 2, associated with a slope declining westwards near the northern end of the paddock. In the *Desmanthus* paddocks, biomass was higher in the apparently more wooded country towards the northern end of Replicate 1 and across the middle of Replicate 2. Higher proportions of *Desmanthus* appeared to be associated with areas of lower biomass (Fig. 4*b*). Cattle presence was concentrated near water points and along fence lines (Fig. 4*c*).

Table 4. Effect of *Desmanthus* inclusion in the pasture and season on nutritive value of pastures and diet estimated from near infrared reflectance.

Item	Wet 1		Dry		Wet 2		s.e.	*P*		
	Control	*Desmanthus*	Control	*Desmanthus*	Control	*Desmanthus*		T	S	T × S
Nutritive value of pasture (% DM unless otherwise stated)										
Nitrogen	0.978	0.907	0.582	0.690	1.08	1.27	0.118	0.342	<0.001	0.411
Neutral detergent fibre	71.6	66.1	76.2	73.2	70.1	67.1	2.304	0.007	<0.001	0.778
Acid detergent fibre	40.7	40.6	46.3	47.0	42.5	41.8	1.203	0.991	<0.001	0.776
Hemicellulose	30.6b	25.4a	29.9	26.1	27.6	25.1	1.742	<0.001	0.315	0.574
DM digestibility (%)	47.2	46.0	41.3	41.4	49.4	48.0	1.531	0.409	<0.001	0.822
Nutritive value of diet (% DM unless otherwise stated)										
Dietary nitrogen	2.06b	1.76a	1.06a	1.23b	2.24b	2.04a	0.023	<0.001	<0.001	<0.001
Faecal nitrogen	1.87a	2.88b	1.43	1.51	1.78a	2.33b	0.023	<0.001	<0.001	<0.001
DM digestibility (%)	59.5b	57.5a	52.9	52.4	60.0a	57.6b	0.222	<0.001	<0.001	<0.001
Non-grass (%)	15.4a	52.4b	21.7	19.4	12.2a	34.4b	0.807	<0.001	<0.001	<0.001

Significant treatment differences within season are indicated by different lower-case letters (at $P = 0.05$).
S, season; T, treatment.

Elsewhere, cattle appeared to prefer wooded, sloping country, as in the northern end of Control replicate 2 and near the excluded area in *Desmanthus* replicate 2. There were large areas of all paddocks where collared cattle never ventured.

In October 2024, corresponding to the late dry season, biomass was lower in all paddocks than in the wet season, but generally those areas of high biomass in March appeared to still be areas of high biomass in October (Fig. 5). The proportions of *Desmanthus* were again lower than in March, particularly in Replicate 2.

Cattle grazing behaviour

Sixteen GPS collars were deployed on 13 March 2024, of which 13 collected complete datasets between the 14 March 2024 and 22 March 2024. Fig. 6 summarises the travel distances by all cattle with GPS collars deployed in the mid-dry season. Travel distance gradually declined over the 86 days of measurement by 20 m/day. The blue bars represent the number of functioning collars over time. Travel distances were reduced on rainy days, and the mustering days clearly showed an increase in travel distance by cattle. There were no treatment differences ($P > 0.05$) in activity, with distance travelled averaging (mean ± s.e.) 10.7 ± 0.44 km/day over the full 86 days of deployment. There was a marked crepuscular pattern in activity (data not shown), with higher activity (~800 m/h) at dawn and dusk. Between 1000 hours and 1600 hours, and overnight cattle were more sedentary, moving between 200 and 300 m/h.

Fig. 7*a* shows the preference ratio for cattle in yield quantiles of 4 t/ha. Values >1 indicate that cattle are attracted to a quantile, whereas values <1 indicate that cattle are avoiding a quantile. For cattle in Control paddocks, preference ratio was not markedly influenced by biomass up to a value of 24 t/ha, although they showed a preference for the 8–12 t/ha and 20–24 t/ha quantiles. Areas of higher biomass were markedly avoided. By contrast, cattle in *Desmanthus* paddocks showed a marked preference for the biomass quantile from 12 to 16 t/ha. Fig. 8*b* shows the same analysis for preference of legume deciles in the *Desmanthus* paddocks. Preference ratios increased as the %legume increased. Although the proportion of the paddock with over 80% legume was less than 5% of the paddock area, cattle had a strong preference for these areas.

Methane emissions

Methane production averaged 186 g/day for the Control treatment and 180 g/day for the *Desmanthus* diet, a difference that failed to reach significance ($P = 0.102$; Table 5). However, when methane was adjusted for estimated DMI (methane yield) or LW (methane intensity), there were significant treatment effects, with both yield and intensity being lower for cattle grazing *Desmanthus* ($P < 0.05$). Season strongly influenced all metrics of methane emissions ($P < 0.001$) with values being markedly higher in the second wet season. The interaction between treatment and season was significant for all metrics of methane emissions ($P < 0.05$), with methane production ($P < 0.10$), yield ($P < 0.10$), and intensity ($P < 0.05$) trending or being lower in the first wet season and methane intensity trending lower in the second wet season ($P < 0.10$) for cattle grazing *Desmanthus*.

Fig. 8 shows the pattern in methane production over the whole trial. Generally, in the wet seasons, methane production from cattle in the *Desmanthus* paddocks was below that from cattle in the Control paddocks. The reverse was apparent in the dry season, presumably because *Desmanthus* cattle were heavier and consumed more feed, and because the low content of non-grass removed any antimethanogenic effect in the dry season. Methane production declined as the dry season advanced (April to October). Methane production in

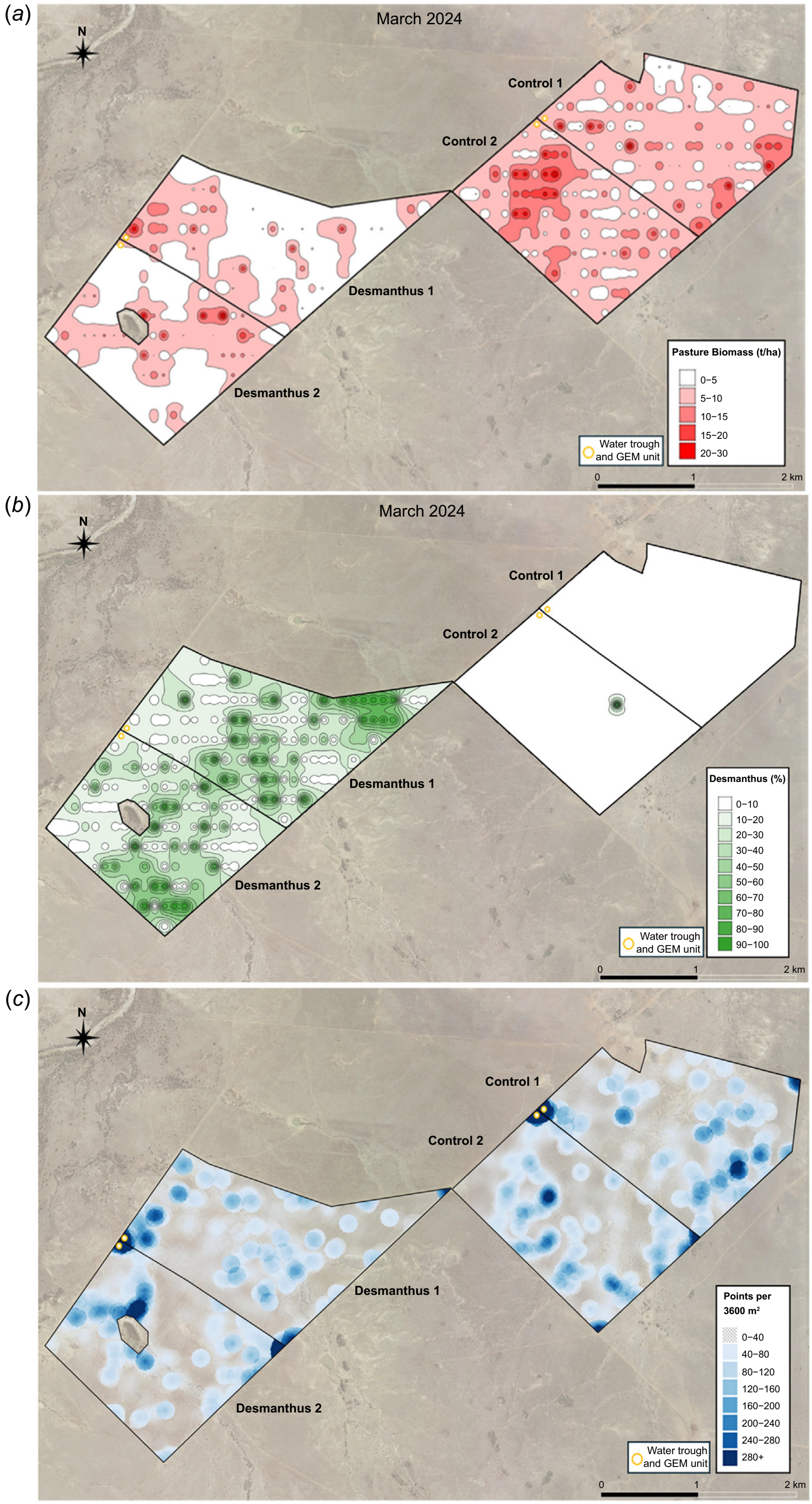

Fig. 4. Spatial heterogeneity of (*a*) pasture biomass and (*b*) *Desmanthus* in the first wet season (March 2024) and (*c*) cattle location from 13 March to 6 June 2024.

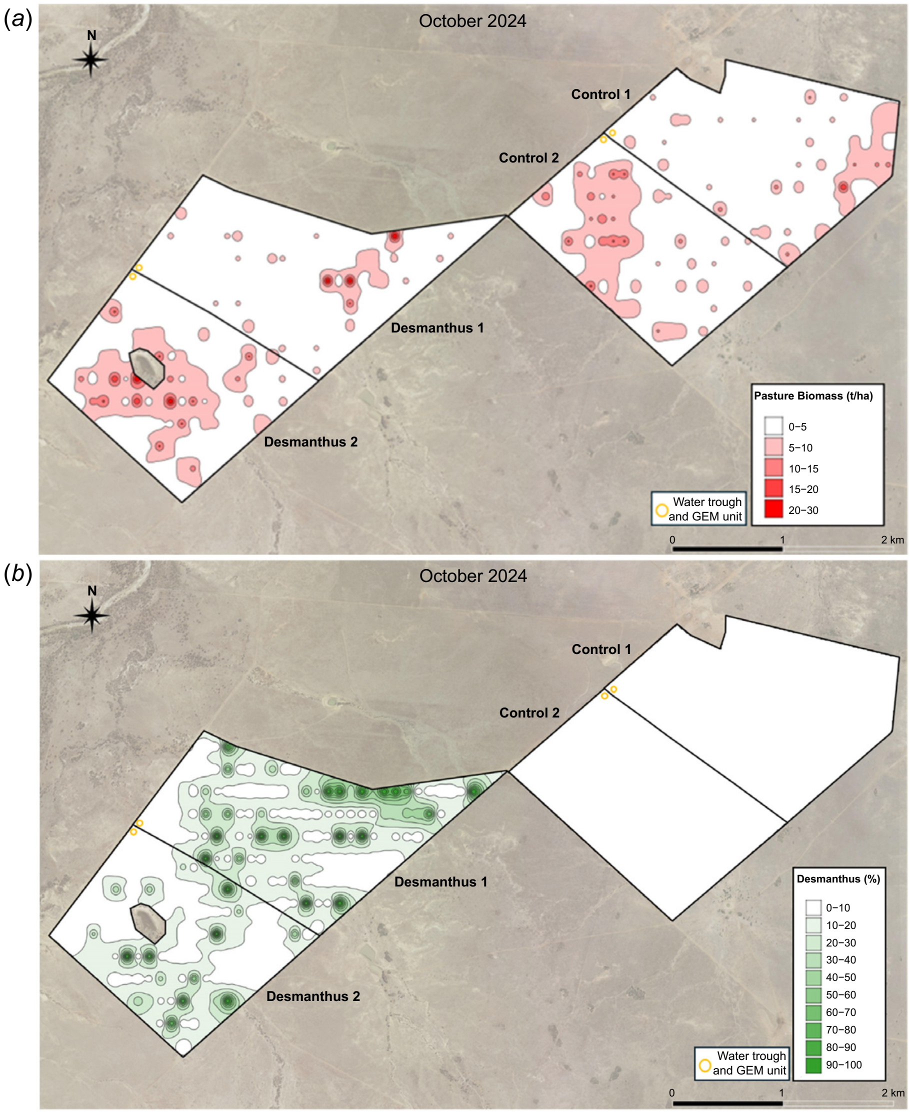

Fig. 5. Spatial heterogeneity of (*a*) pasture biomass and (*b*) *Desmanthus* in the dry season (October 2024).

the second wet season was approximately 50% greater than in the previous seasons.

Discussion

Animal performance

The response to a treatment is always relative to the control and, in the case of buffel grass pastures, the performance of cattle on the control treatment (233 kg of LWG over the first 12 months of the study) was higher than the regional average for improved Brigalow of 183 kg/year (Bortolussi *et al.* 2005). The improvement in annual turnoff weights of Control cattle could be explained through the genetic improvement of cattle between 2005 (publication date for Bortolussi *et al.* 2005) and 2025 (Hammond 2006), and the high nutritive value of the buffel grass, coupled with the low stocking rates of ~4 ha/AE relative to the feed on offer (4–8 t/ha). These conditions allowed cattle to select the more nutritious plant components of the buffel grass. Thus, the animal growth response to inclusion of *Desmanthus* in the pasture was less than reported by others (Gardiner and Parker 2012; Godson *et al.* 2024) and also less than seen with other legumes such as stylos (Bowen and Rickert 1979; Hill *et al.* 2009) or *Leucaena* (Harrison *et al.* 2015).

Whereas the diet quality and high performance of Control cattle would have minimised any response to legume inclusion, it was also apparent that any growth response in cattle grazing *Desmanthus* pastures occurred in the wet seasons, when *Desmanthus* was actively growing and carrying leaf. We speculated that in the presence of good quality buffel grass, cattle may not be selecting *Desmanthus* in their diet in

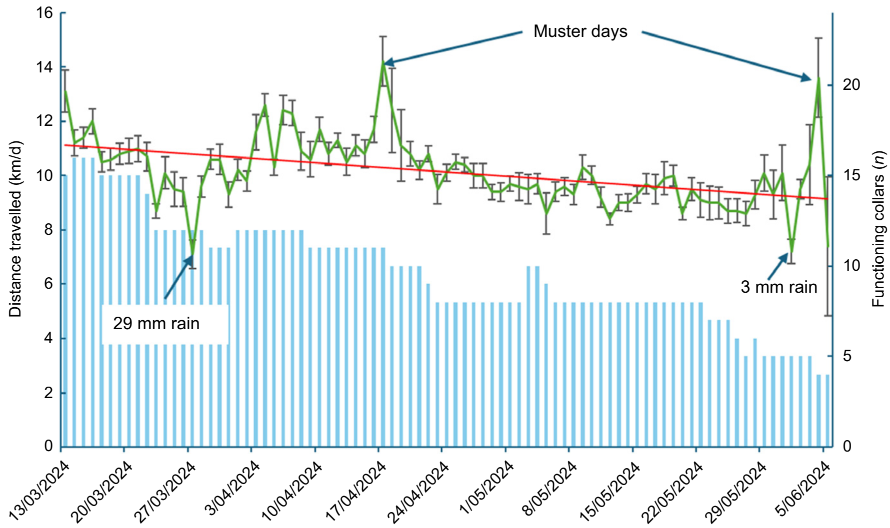

Fig. 6. Mean distance travelled (all paddocks combined) by cattle with functioning collars throughout the duration of the collar deployment (green line, ±s.e.). The red line represents the linear relationship given by the equation $Y = -0.2x + 10.79$ ($R^2 = 0.20$), where Y is distance travelled in km, and x is days of collar deployment. The blue bars represent the number of functioning collars.

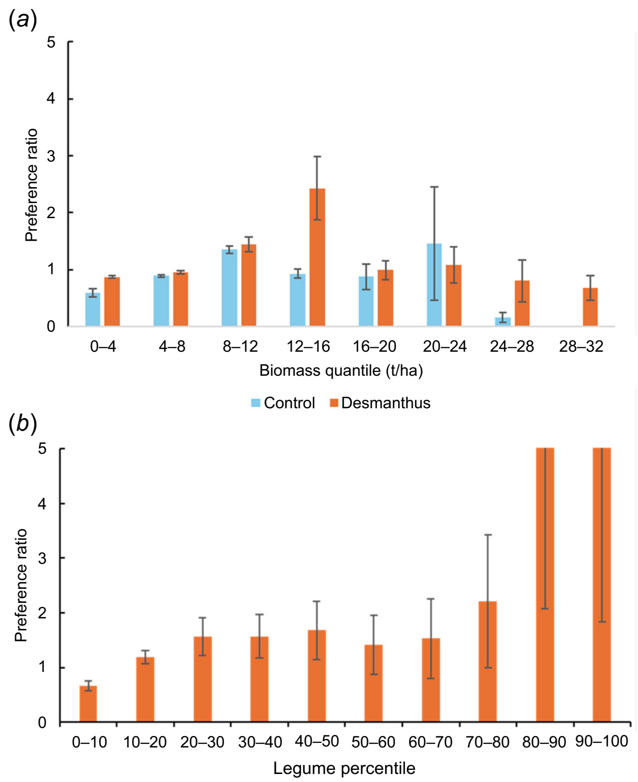

Fig. 7. The preference ratio for the presence of cattle within (*a*) biomass yield quantile (t/ha) and (*b*) legume percentile (%legume).

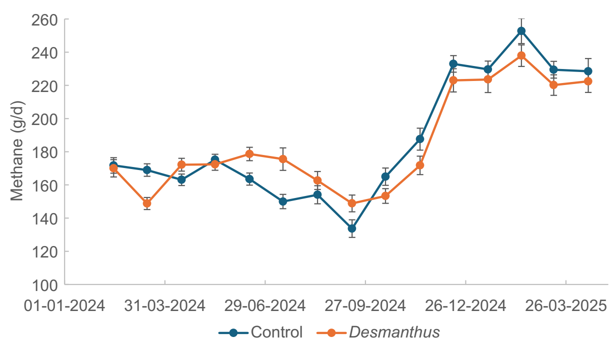

Fig. 8. Mean monthly methane production for selected cattle grazing Control or *Desmanthus* pastures.

the drier months. This was confirmed by the similarity across treatments in %non-grass (likely to be *Desmanthus*) estimated by faecal NIR in the diet during the dry season. However, for samples collected during the first wet season when *Desmanthus* cattle were outperforming those on buffel grass, there was a three-fold increase in %non-grass in the diet, suggesting that cattle were selecting *Desmanthus* at this time. In the second wet season, the non-grass component of the diet for *Desmanthus* cattle was numerically smaller than in the first wet season, but still higher than for cattle on Control pastures. However, there was no response in animal gain, possibly because cattle were approaching mature weights and were less responsive to any increased undegraded protein supply to the lower intestine arising from the inclusion of a tanniniferous legume (Kelln *et al.* 2023).

Pasture and diet nutritive value

As noted in previous research (Charmley *et al.* 2024), cattle selected diets of higher nutritive value than that of the

Table 5. Effect of *Desmanthus* inclusion in the pasture and season on estimated DM intake, methane production, methane yield and methane intensity.

Item	Wet 1		Dry		Wet 2		s.e.	*P*		
	Control	*Desmanthus*	Control	*Desmanthus*	Control	*Desmanthus*		T	S	T × S
Estimated DM intake (kg/day)	5.42	5.56	6.64	6.75	7.76	7.88	0.041	<0.001	<0.001	0.847
Methane production (g/day)	171B	158A	158	165	227	215	4.68	0.102	<0.001	0.037
Methane yield (g/kg DM intake)	30.5B	28.0A	23.6	24.6	29.0	27.2	0.736	0.048	<0.001	0.035
Methane intensity (g/kg LW)	0.565b	0.515a	0.404	0.415	0.473B	0.437A	0.013	0.012	<0.001	0.036

Significant ($P < 0.05$) treatment differences within season are indicated by different lower-case letters (at $P = 0.05$).
Treatment differences ($P < 0.10$) within season are indicated by different upper-case letters (at $P = 0.10$).
S, season; T, treatment.

pasture. Dietary N was almost twice the concentration in the diet with the pasture, and DM digestibility was nearly 30% higher. The relationship among biomass, diet quality and performance in grass swards is complex. Chacon *et al.* (1978) showed that cattle graze in horizons, with the upper horizon, grazed preferentially, having the highest proportion of leaf: stem ratio. At low stocking rates and high biomass, as for cattle grazing 90% plus buffel grass pastures in the current trial, cattle will preferentially graze the more nutritious upper horizon. Da Silva *et al.* (2024) demonstrated that as sward height increased, DMI and LWG also increased because of increased bite mass associated with greater biomass availability.

In grass–legume swards, the pasture–animal interface is further complicated because cattle may selectively choose legumes over grasses and exhibit higher intake of the mixed diet owing to differences in fibre and CP composition of the legume (Niderkorn and Baumont 2009). Evidence derived from the estimation of non-grass proportions in the wet-season diet in the current trial suggested that cattle did select legume, even though the digestibility and N content of the grass–legume diet were lower than those of the high-grass diet.

The lower biomass of *Desmanthus* swards was unexpected. Research has shown that including legumes such as stylos (Noble *et al.* 2000; Hill *et al.* 2009), *Leucaena* (Dixon and Coates 2008) and *Desmanthus* (Mwangi *et al.* 2021) into tropical pastures generally results in increased biomass. All four paddocks were located on similar soils and were established stands of buffel grass, although the buffel grass was more recently established in control paddocks than in *Desmanthus* paddocks. Buffel productivity decline in the longer-established *Desmanthus* paddocks may have been a contributory factor (Meat and Livestock Australia 2017). Glyphosate used on buffel grass to assist establishment of *Desmanthus* in 2019 may have had long-term effects on buffel grass vigour, particularly in the drier than normal seasons of the study.

It was anticipated that the N content of the *Desmanthus* would have been higher than that of the buffel grass. Mwangi *et al.* (2022), with plot-grown *Desmanthus*, noted that N content of Progardes *Desmanthus* declined from approximately 3% to 2.5% with advancing maturity and changes in the leaf:stem ratio. It was noted that the N content of stem was approximately one-third of that of the leaf. The N content of the 90% plus buffel grass sward, although high (2.2% DM) for a tropical grass, was still lower than the value for *Desmanthus* reported by Mwangi *et al.* (2022). Several explanations are possible for this conflicting evidence. First, it was noted that biomass was lower in *Desmanthus* paddocks, which could have forced cattle to consume lower-quality buffel grass in the *Desmanthus* paddocks (Da Silva *et al.* 2013). Second, the N content of consumed *Desmanthus* may have been less than expected if cattle were consuming a disproportionate amount of stem relative to the whole plant.

These contrasting influences of the two treatments would have affected intake and performance. In the control treatment, intake and performance were maximised owing to the lax grazing intensity of approximately 4 ha/AE, whereas in the *Desmanthus* treatment, performance may have been curtailed by the antagonistic influences of increased intake potential and lower nutritive value.

The ratio between faecal and dietary N was greater in the wet seasons for cattle grazing *Desmanthus* pastures (1.6) than for those grazing buffel grass pastures (0.9). The relative higher faecal N in cattle on *Desmanthus* pastures may be related to the tannin content of *Desmanthus* and further confirms the theory that, at this time, cattle were selecting *Desmanthus* in their diet. Condensed tannins are known to bind protein, leading to higher N loss in faeces and lower N loss in urine (Mueller-Harvey *et al.* 2019), with the effect being related to both the concentration and molecular weight of the condensed tannin (Naumann *et al.* 2013). Whereas condensed tannins were not measured in this study, results from previous work with *D. leptophyllus, D. virgatus* and *D. bicronutus* suggest that concentrations between 3% and 7% would be typical (Suybeng *et al.* 2020; Suybeng *et al.* 2021), although higher concentrations have also been observed in *D. illinoensis* (Naumann *et al.* 2013).

Temporal and spatial distribution of pasture and cattle

In the current trial, availability and functionality of collars limited the number of functioning collars to 12 (three per paddock). Using a small sample size to represent behaviour may limit the applicability of data to the whole herd (Harris *et al.* 2007). However, variation in travel distance (11.3 ± 0.24 km; mean ± s.e.) across all functioning collars was small, suggesting similarity among individuals in activity. Studies have used similar numbers of cattle for behavioural studies (Augustine *et al.* 2022). It had been demonstrated that high GPS fix rate and long observation periods, as used in our study, enhance the accuracy of data (Johnson and Ganskopp 2008). Thus, although there is confidence in the data collected for individual animals, it remains uncertain if this behaviour is representative of the whole group. Grazing theory suggests that cattle tend to spend more time close to water points and less time further away (Hunt *et al.* 2014), resulting in depleted biomass near waterpoints. Generally, cattle are reluctant to be more than 5 km from water and this can effectively reduce the home range to be less than the area of the paddock (Hunt *et al.* 2007). This was not apparent in this study, where the maximum distance to water was <5 km and distribution of biomass was independent from proximity to water.

The presence of cattle in an area does not equate to grazing, but the technology available at the time was not able to differentiate specific grazing activity. Subsequent versions of the CSIRO collar now have the capacity to measure grazing time and location and would have been useful in the current trial (Arablouei *et al.* 2024). Thus, it was not possible to definitively relate preference to time spent in an area with grazing. However, it appeared that cattle were optimising their grazing behaviour to maximise performance, at least for the Control cattle. At the end of the wet season, activity of Control cattle appeared to be greatest around areas of high biomass, according to visualisation of contour maps. This was supported by analysis of the preference ratio that showed that cattle spent proportionally more time in the 8–12 t/ha and 20–24 t/ha biomass quantiles. This level of biomass would support the selective grazing of the upper grazing horizon (Chacon *et al.* 1978) without dilution with stem associated with areas of higher biomass where the rank nature of the buffel grass would deter grazing (Benvenutti *et al.* 2009). It was also apparent that they avoided areas of low biomass (<4 t/ha) where intake would be compromised because of small bite size (Da Silva *et al.* 2013). Thus, Control cattle were maximising intake of grass components highest in digestibility and N content.

The situation was more complex for *Desmanthus* cattle, where it appeared that cattle may be selecting for *Desmanthus* and eliciting a nutritive value penalty, according to their faecal NIR results. Nonetheless, hot carcase weights were 10 kg greater for *Desmanthus* cattle and this increased carcase value by A$70/head. Because the intake of *Desmanthus* is presumed critical in controlling the level of methane mitigation, the temporal and spatial distribution of grass, legume and cattle was explored using geolocation in the transition period between the wet and dry season in 2024. For cattle in *Desmanthus* paddocks, total biomass was overall lower than in Control paddocks, and cattle compensated by spending a greater proportion of time in areas of higher biomass. Throughout the two *Desmanthus* paddocks, there were small areas of very high *Desmanthus* content (>80%). Although these areas accounted for only 2.5% of the total paddock area, the cattle exhibited a strong preference for these areas. Their preference for these areas could explain why *Desmanthus* intake was apparently disproportionately high in the wet seasons. It is concluded that the presence of *Desmanthus* in the pasture influenced grazing activity, with cattle selecting for *Desmanthus*, possibly at the expense of maximising intake and nutritive value.

Measurement and interpretation of methane emissions

The cattle that self-selected for methane measurement did not differ in LWG (0.64 kg/day; $P = 0.54$), half-carcase weight (150 kg $P = 0.09$) or P8 fat ($P = 0.59$) from cattle not being recorded for methane emissions. This gives confidence that access to GEMs did not in any way affect indices of cattle performance. The contribution of pellets to total dietary intake was estimated at approximately 6% for both CP and ME. Over the duration of this study, methane yield was 23% higher (25.6 g/kg DMI) than measurements made on confined Australian cattle fed diets of >70% forage by using open-circuit respiration chambers (Charmley *et al.* 2016). Whereas differences between respiration chamber and GEM methods have been observed within the same trial (Jonker *et al.* 2016), in a subsequent meta-analysis Jonker *et al.* (2020) fount no difference between methane yield measured in respiration chambers (21.6 g/kg DMI) and that measured in GEM units (22.8 g/kg DMI). To estimate methane yield in the paddock requires an accurate estimation of DMI. Feed intake is the main determinant of methane production (Van Lingen *et al.* 2019) and LW and its rate of change is positively correlated with DMI for tropical pasture species (Minson and McDonald 1987). The equation derived by (Minson and McDonald 1987) for cattle fed tropical diets is used to predict national methane emissions for inventory purposes by the Australian Government (2024) and it was also used in this study. However, this equation is almost 40 years old and may not accurately predict intake of modern cattle (Hammond 2006). McLennan (2020) created a model that that includes diet quality, animal characteristics and animal performance (QuikIntake, ver. 6, 2019) and Charmley *et al.* (2023) found that using this equation on grazing steers estimated DMI to be approximately 18% higher than that from using the equation of Minson and McDonald (1987). Thus, if the QuikIntake method is used to estimate DMI, then methane yield is reduced to approximately 21 g/kg DMI, a value similar to the inventory value.

It was evident that compensatory gain was potentially influencing performance of cattle during the first wet season.

These cattle transitioned from a low plane of nutrition in the Northern Territory to a high-quality forage in central Queensland. Under such conditions, cattle exhibit higher than expected rates of LWG relative to intake (Silva *et al.* 2022). This has been variously attributed to lean deposition with the associated water, re-alimentation of the digestive tract and a reduced maintenance requirement (Berge 1991; Mota *et al.* 2020).

A more appropriate method for scaling methane emissions of growing cattle is to use methane intensity. In this trial, methane per unit LW was chosen, because LW was accurately measured and readily available. Unfortunately, the literature at large does not routinely publish these data, thus it is not a useful metric for comparison with other publications. This method was able to differentiate the wet season–dry season dichotomy in methane mitigation arising from *Desmanthus* inclusion in the diet of growing cattle. Methane intensity measured as CO_2-e per kilogram hot carcase weight for the period of methane measurement was 7.5 versus 7.1 kg for Control and *Desmanthus* cattle respectively. These values were lower than those typically expected of approximately 12–15 Mg CO_2-e per kilogram hot carcase weight, because the data did not encompass lifetime emissions for these cattle (Meat and Livestock Australia 2020).

Effect of *Desmanthus* on methane emissions

A significant challenge of evaluating the effect of antimethanogenic pasture species on methane emissions in the field is the relatively small reductions in methane emissions, coupled with a high variance in the data. In the current study, observations were made on almost 100 individuals over a 16-month period. The design was also unbalanced owing to different numbers of cattle successfully utilizing GEM units in the four paddocks.

Over the entire study, methane production was not significantly influenced by *Desmanthus*, although the overall 3% reduction just failed to show a trend ($P = 0.102$). Although numerical differences were observed in most monthly means, it remained difficult to demonstrate significant treatment differences in methane production. Nevertheless, there was an interaction between treatment and season, such that *Desmanthus* tended to reduce methane production and yield in Wet season 1, but this was offset by greater methane production in the dry season. The effect of *Desmanthus* was more pronounced when methane was expressed relative to LW. *Desmanthus* increased LWG in the first wet season, such that cattle were some 12 kg heavier than were cattle grazing buffel grass. This difference in LW, that was sustained through the remainder of the study, was probably the reason why methane production was greater for *Desmanthus* than Control cattle in the dry season. In the second wet season, this effect would still be apparent but was counteracted because of lower methane yield attributed to the antimethanogenic activity of *Desmanthus*.

As noted earlier, there are issues regarding the magnitude of methane yield (g/kg DMI) when there is uncertainty around the intake estimation; however, the treatment comparisons have validity. Overall, *Desmanthus* in the diet reduced methane yield in the wet seasons, when *Desmanthus* was a major dietary component, compared with the dry season, when *Desmanthus* comprised a much smaller component of the diet. Two intensive studies using open-circuit respiration chambers have been conducted with *Desmanthus* in Australia. In the first study, Suybeng *et al.* (2020) observed a linear reduction in methane yield as the proportion of *Desmanthus* in the diet increased from 0% to 31%. For every percentage increase in *Desmanthus*, the methane was reduced by 0.066 g/kg DMI. Thus, for a 31% inclusion, methane yield was reduced by approximately 10%. This value is somewhat greater than observed under field conditions in our study. However, Suybeng *et al.* (2020) fed low-quality Rhodes grass hay ($N = 1.4\%$ DM, $ME = 6.2$ MJ/kg DM) and it was observed that adding the *Desmanthus* to the diet increased total volatile fatty acid (VFA) concentration in the rumen and increased the acetate:propionate ratio. Whereas increased ruminal activity (evidenced by the VFA concentration) was expected by the addition of an N source, the increased the acetate:propionate was contrary to expectations. Typically improving the nutritive value of the diet should favour propionate production over acetate in the rumen and reduce methane, as propionate is a H_2 acceptor (Benchaar *et al.* 2001). It was also noted that adding polyethylene glycol (PEG) to the diet did not affect methane production. The PEG bonds with phenolic and hydroxyl groups in tannins, thus reducing their influence on methanogenesis (Silanikove *et al.* 2001). In the absence of a tannin or a VFA effect, it was speculated that when a higher-quality legume is included in a poor-quality hay diet, rumen outflow rate may be increased, thus reducing methane (Goopy *et al.* 2020). In a subsequent study, Suybeng *et al.* (2021) examined the substitution of 30% lucerne (presumed to be non-antimethanogenic) with *Desmanthus* in Rhodes grass hay diets of higher nutritive value (N = 2.3% DM, DMD = 60%) to the hay used by Suybeng *et al.* (2020). Here, substituting lucerne with *Desmanthus* reduced diet nutritive value, DMI, and methane production; however, there was no effect on methane yield. Recent evidence suggests that lucerne may have a small antimethanogenic effect (~5% reduction) owing to the presence of saponins (Li *et al.* 2025). This would have masked any antimethanogenic effect of *Desmanthus*.

Clearly, the limited published *in vivo* literature on *Desmanthus* demonstrated equivocal results suggesting that several mechanisms may be influencing methane production and yield depending on a range of conditions such as the nutritive value of the companion forage, the level and composition of tannins in *Desmanthus* and the feeding level. By contrast, the relatively larger amount of *in vitro* data clearly supports the view that *Desmanthus* can reduce methane emissions. E. Mitchell, B. Henry, G. Peck, E. Charmley, P. Grace and R. Eckard (unpubl. data) in a recent review of tropical legumes, identified three species of *Desmanthus* that reduced *in vitro* emissions (g/mL DM incubated) by 10–30%. Of all tropical legumes compared, *Desmanthus* species were among the most effective at reducing methane *in vitro*. The current data support the hypothesis that *Desmanthus* can reduce methane yield *in vivo*. Indirect evidence suggests that the amount of *Desmanthus* in the diet is linked to the mitigation effect. Our data and the published *in vivo* data are unable to definitively ascribe a cause to what is likely to be a modest reduction in emissions (~5–10%). Most likely, a number of conditions are implicated including tannins, rumen fermentable energy sources, and rumen turnover rates, depending on the nature of the diet and the physiological status of the animal.

Considerations for on-farm adoption of *Desmanthus*

In a recent review, Charmley *et al.* (2025) suggested that there was a major opportunity for more widespread adoption of *Desmanthus* into grazing systems across northern Australia. In 2023, it was estimated that *Desmanthus* had been introduced to approximately 100,000 ha, and there are approximately 35 million hectares of suitable soils. Limited animal performance data for cattle grazing pastures with *Desmanthus* would suggest a production response of between 0% and 30%, resulting from a combination of increased stocking rates and individual animal LWGs (Gardiner and Parker 2012; Collins *et al.* 2016; Mwangi *et al.* 2021; Godson *et al.* 2024). Thus, with increased adoption, even the modest reduction in methane emissions observed in this study could have a major impact on the annual enteric emissions from cattle in northern Australia. However, it is possible, that on a property scale, introduction of a low-emissions forage could increase total methane production as measured in metric tonnes per property or hectare if the response in LWG (and hence animal equivalents) is greater than the reduction in methane yield (g/kg DM intake). In the current study, this was not the case because of the small but significant productivity response to *Desmanthus* inclusion in the pasture. The opportunity to claim for avoided emissions through current and future carbon initiatives should account for these interactions between methane production and intensity Finally, the opportunity to claim soil carbon sequestration benefits in addition to avoided methane emissions could be considered in holistic carbon balance accounting in the future (Takeda *et al.* 2025).

Conclusions

Desmanthus can reduce methane yield (methane per unit of intake) and methane intensity (methane per unit animal product) in grazing cattle. However, the reduction is modest and highly dependent on the quality and species of the companion forage(s), the proportion of *Desmanthus* in the diet and the proportion of the year when *Desmanthus* is actively growing and selected for by grazing cattle. Any reduction in methane yield or intensity can be negated by higher total emissions because of a positive response in LWG, attributed to the higher nutritive value of the *Desmanthus*. Collectively the impact on turnoff rates and methane emission reduction can have economically important benefits for the northern beef industry. However, this work has shown that a production response to *Desmanthus* inclusion in the pasture can be modest, depending on the grazing intensity and nutritive value of the control treatment. Further work is required under a range of production scenarios to maximise the economic and environmental benefits of including *Desmanthus* in grazing systems.

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Data availability. Data used to generate the results in the paper will be shared upon reasonable request to the corresponding author.

Conflicts of interest. N. Kempe is a director of Agrimix (formerly Agrimix Pastures, Pty, Ltd), a company developing commercial agricultural technology platforms for climate abatement opportunities. The authors have no further conflicts of interest to declare.

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