

Scotland's Rural College

## Ubiquitous parasites drive a 33% increase in methane yield from livestock

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1 **Ubiquitous parasites drive 33% increase in methane yield from livestock**

2

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24 **Abstract**

25 Of anthropogenic methane emissions 40% can be attributed to agriculture, the majority of which  
26 are from enteric fermentation in livestock. With international commitments to tackle drivers of  
27 climate change, there is a need to lower global methane emissions from livestock production.  
28 Gastrointestinal helminths (parasitic worms) are globally ubiquitous and represent one of the  
29 most pervasive challenges to the health and productivity of grazing livestock. These parasites  
30 influence a number of factors affecting methane emissions including feed efficiency, nutrient  
31 use, and production traits. However, their effects on methane emissions are unknown. This is the  
32 first study that empirically demonstrates disease-driven increases in methane (CH<sub>4</sub>) yield in  
33 livestock (grams of CH<sub>4</sub> per kg of dry matter intake). We do this by measuring methane  
34 emissions (in respiration chambers), dry matter intake (DMI), and production parameters for  
35 parasitised and parasite-free lambs. This study shows that parasite infections in lambs can lead to  
36 a 33% increase in methane yield (g CH<sub>4</sub>/kg DMI). This knowledge will facilitate more accurate  
37 calculations of the true environmental costs of parasitism in livestock, and reveals the potential  
38 benefits of mitigating emission through controlling parasite burdens.

39

40 Key words: methane, greenhouse gas, climate change, parasites, disease; lambs

41 **1. Introduction**

42 Strategies for minimising global greenhouse gas (GHG) emissions from livestock systems are  
43 vital. Agriculture contributes an estimated 18% of GHG emissions (Steinfeld et al., 2006), with  
44 approximately half of these emissions coming from meat and dairy (Garnett, 2009). Emissions  
45 are a particular concern in small ruminant (sheep and goat) milk and meat production as 56% of  
46 the global domestic ruminant population are small ruminants (Marino et al., 2016), and enteric  
47 fermentation is responsible for the majority of emissions in these systems (Gerber et al., 2013).  
48 Minimising GHG emissions from livestock systems will become increasingly important as  
49 demand for livestock products grows; by 2050 the global sheep population is expected to  
50 increase by 60%, from 1.7 billion in 2000 to about 2.7 billion by 2050 (Foresight, 2011). With  
51 little chance of decreasing emissions through an overall reduction in the numbers of farmed  
52 ruminants, other ways to mitigate ruminant methane emissions are required (Herrero et al., 2016;  
53 Dangal et al., 2017).

54  
55 The primary factors affecting ruminant enteric methane emissions are thought to be feed intake  
56 levels, feed composition, and the microflora of the rumen (Lascano & Cárdenas, 2010).  
57 Consequently, mitigation options currently fall into three broad categories: 1) animal breeding  
58 for improved efficiency; 2) feed supplements and feed management; and 3) rumen control and  
59 modifiers (Marino et al., 2016). However, a number of these strategies have high costs and/or  
60 inconsistent effects (Marino et al., 2016) and reliable, affordable technologies for reducing  
61 methane emissions in grazing livestock in a way that improves overall farm productivity and  
62 efficiency remain elusive.

63

64 Gastrointestinal helminths are globally ubiquitous, offering the most pervasive challenge to all  
65 grazing livestock worldwide and compromising animal health, welfare and production  
66 efficiency. They have a substantial impact on the majority of the factors affecting methane  
67 production, including feed intake levels, nutrient use, and rumen retention time (Houdijk et al.,  
68 2016). Controlling gastrointestinal parasites could potentially reduce GHG emissions in grazing  
69 livestock. However, their effects on methane emissions are currently unknown.

70

71 In addition to revealing the mitigation potential of reducing parasitism, understanding the impact  
72 of parasitism on methane production is also vital in calculating the true extent of GHG emissions  
73 from livestock. Many studies have attempted to calculate the GHG emissions from livestock  
74 systems, often with the aim of quantifying how changes in efficiency will impact on methane  
75 production (Kipling et al., 2016; Özkan et al., 2016). Emissions estimates are generally  
76 calculated based on livestock numbers, time in the production system, and basic national  
77 multipliers. However, such calculations ignore the potential impacts of common infections.  
78 Efforts have been made to explore the impacts of parasitism on production efficiency and time  
79 on pasture, and the consequent implications for emissions (Kenyon et al., 2013). However this  
80 approach assumes that methane yield remains constant regardless of infection status, and that  
81 parasitism has no additional effect beyond the higher overall feed intake due to decreased  
82 production efficiency and increased time to slaughter.

83

84 By quantifying how parasitism affects methane emissions per unit of feed intake, we can obtain a  
85 more complete understanding of the environmental costs of parasitism and the potential benefits  
86 of mitigating emission through controlling parasite burden. Here, we address this aim by

87 evaluating methane emissions per unit of feed intake in parasitised and non-parasitised finishing  
88 lambs, using respiration chambers.

89

90

## 91 **2. Materials and methods**

92 **The protocol was conducted under Home Office licence (PPL 60/4489) and was approved**  
93 **by SRUC's Animal Experiment Committee (AE ED 24-2015).**

94

### 95 *2.1 Animals and experimental design*

96 A total of 72 parasite naïve lambs (Suffolk x Mule), 12-15 weeks old were selected from a  
97 commercial sheep flock. All animals were expected to be parasite naïve at the start of the trial,  
98 as they were reared indoors and only fed commercial pelleted feed. Their parasite free status was  
99 confirmed using faecal egg counts. The animals were divided into three treatment groups,  
100 balanced for live weight (mean body weight at day 0 = 36.62kg ±0.35 S.E.) and sex (mixed  
101 pens). These treatments were: *Ad lib* fed control ; restricted-fed control ; and parasitised .

102

103 There were a total of eight replicates for each treatment, with each replicate comprised of one  
104 pen of three lambs. There were three lambs in each pen to ensure adequate eructation for  
105 methane detection. The lambs were housed in indoor pens in these groups of three for the  
106 duration of the trial. The trial lasted for 39 days and animals were returned to stock at the end of  
107 the trial.

108

109

## 110 2.2 Parasite challenge

111 The animals in the parasitised treatment were trickle challenged with 7,000 infective  
112 *Teladorsagia circumcincta* larvae suspended in 10ml of water, three times a week from days 0 to  
113 35 (five weeks). *T. circumcincta* is an abomasal nematode which represents a substantial  
114 parasitic challenge to sheep, and is often linked with parasitic gastroenteritis in lambs (Coop et  
115 al., 1982). The trickle infection was used to represent the challenge encountered by grazing  
116 lambs, and was expected to result in subclinical infection consistent with rates of natural  
117 infection on moderately parasitised pasture (Coop et al., 1982). The *ad lib* control, and  
118 restricted-fed control treatments were sham infected with 10ml of water, following the same  
119 protocol as the parasitised treatment. Parasite levels were monitored through weekly faecal  
120 sampling for faecal egg counts (FEC), using the modified flotation method with a sensitivity of 1  
121 egg per gram of faeces (epg)(Christie & Jackson, 1982). To give an indication of gut damage by  
122 *T.circumcincta*, pepsinogen levels were measured from blood samples taken at three points in the  
123 trial. Blood samples were collected from all animals at day 0 (pre-challenge), day 36 (peak  
124 challenge, prior to being placed in the respiration chambers), and day 39 (after removal from the  
125 respiration chambers).

126

## 127 2.3 Feeding

128 The *ad-lib* control and parasitised treatments were fed *ad-lib* access to pelleted grass. The  
129 restricted fed treatments were fed 80% of the intake of their *ad lib* fed counterparts, relative to  
130 body weight. Parasite induced anorexia was expected in the parasitised treatment, hence the  
131 restricted-fed control group enabled the assessment of the impact of parasitism *per se* versus that  
132 of anorexia associated with parasitism. All lambs were fed their rations once a day.

133

## 134 *2.4 Measurements*

135

### 136 *2.4.1 Methane*

137 From days 43 to 46 lambs were housed in indirect open-circuit respiration chambers (No  
138 Pollution Industrial Systems Ltd., UK). The trial was conducted over four rounds, using six  
139 respiration chambers, with treatments balanced across each round so that each treatment was  
140 tested in two respiration chambers per round. The area of each chamber is 25.4m<sup>2</sup> with penning  
141 for three lambs. Temperature and humidity were set at 15 ± 1°C and 60 ± 5% respectively, and  
142 air was removed from the chambers by exhaust fans set at 50litres/s. Methane concentration was  
143 recorded for the air in each chamber once every six minutes, using infrared absorption  
144 spectroscopy. Animals remained in the chambers for three full days (days 43 to 46), the first 24  
145 hours were the adaptation period, and measurements taken during the final 48 hours (days 44-46)  
146 were used to quantify methane production. Total feed intake in the chambers was measured  
147 daily, and methane yield (g CH<sub>4</sub>/kg DMI) was calculated by dividing daily methane production  
148 by the daily DMI.

149

### 150 *2.4.2 Digestibility*

151 The collection of faeces directly from the rectum of all lambs was carried out over three  
152 consecutive days (days 30 to 32), pooled per lamb, and stored at -20°C prior to digestibility  
153 analysis. Acid insoluble ash (AIA) was used as an internal, indigestible marker to assess the  
154 apparent total tract digestive matter (DM). Faecal and feed AIA were analysed using the 2N HCl



155 procedure (Van Keulen & Young, 1977). During feeding, feed samples were collected daily and  
156 pooled for analysis.

157

#### 158 *2.4.3 Feed intake and weight gain*

159 Pelleted feed intake was measured three times a week, to calculate the restricted-feeding  
160 allowances. Feed intake was also measured daily in each respiration chamber for calculation of  
161 methane yield (gCH<sub>4</sub>/kg DMI). All lambs were weighed weekly.

162

#### 163 *2.5 Statistical analysis*

164 Data were analysed using ANOVA, with round as the block term. For statistics pertaining to  
165 body weight, day 0 body weight was included as a covariate. Daily intake values are presented  
166 per animal, by dividing the total pen intake by three. All statistical analyses were performed in  
167 GENSTAT 16

168 **3. Results**

169 3.1 Development of the parasite challenge

170 Lamb FEC increased over time for the parasitised treatment, indicating that parasite infections  
171 were achieved in the groups dosed with *T. circumcincta*, whilst the control and restricted-fed  
172 control treatments remained parasite free for the duration of the trial (Fig. 1a). Pepsinogen levels  
173 were significantly higher in the parasitised group at the two sample points in the final week of  
174 the trial ( $P<0.001$ ) (Fig. 1b). These increased levels of blood pepsinogen confirmed abomasal  
175 damage in the parasitised animals compared to the controls. The FEC and pepsinogen results  
176 indicate that the parasitised treatment group did harbour helminth infection when in the  
177 respiration chambers, whilst the *ad lib* and restricted fed control groups did not. No clinical  
178 signs of parasitism were observed in any groups throughout the experiment.

179

180 3.2 Lamb performance

181 Table 1 shows the variation in performance, feed intake, and digestibility, across the three  
182 treatment groups. The DMI of the parasitised group was significantly lower than the *ad lib*  
183 group ( $P<0.001$ ), indicative of parasite induced anorexia with their feed intake being an average  
184 of approximately 80% of the *ad lib* control group over the study period. Maximum anorexia  
185 was found in the final week of the study, where average daily DMI per animal in the parasitised  
186 group was approximately 70% of the *ad lib* control group. The highest level of inappetance  
187 coincided with the time of highest FEC. Average body weight gain was 174 g/day in control *ad*  
188 *lib* fed individuals, whilst the average body weight gain for *ad lib* fed parasitised individuals was  
189 7 g/day.

190

191 3.3 Methane output and yield

192 Methane output was significantly higher in the *ad lib* fed control group ( $P<0.001$ ), than in the  
193 other two treatments (Fig. 2). Whilst methane emissions remained relatively steady over time in  
194 the two *ad lib* fed treatments (*ad lib* control and parasitised), in the restricted fed group the  
195 emissions rose steadily shortly after feeding time, before reaching a peak and declining again.

196

197 Although total methane emissions were highest in the *ad lib* fed control group, Fig. 3 reveals that  
198 methane yield ( $\text{g CH}_4/\text{kg DMI}$ ) was significantly higher in the parasitised group. Methane yield  
199 was 33% higher in the parasitised lambs compared to the *ad lib* control group. Whilst there was  
200 a significant difference in methane yield between the parasitised treatment group and both  
201 control treatment groups ( $P<0.001$ ), there was no significant difference in methane yield  
202 between the *ad lib* fed control group and the restricted-fed control group despite a significant  
203 difference in feed intake (Fig. 3).

204 **4. Discussion**

205

206 This study aimed to quantify the impact of parasitism on methane emissions in lambs. Our  
207 results show that methane yield was 33% higher in the parasitised lambs relative to the *ad lib*  
208 control group. This is the first study to demonstrate that infectious disease can increase methane  
209 yield (g CH<sub>4</sub>/kg DMI).

210

211 The total quantity of methane produced per day was highest in the *ad lib* control group (Fig. 2).  
212 This is because the primary driver of methane production (g CH<sub>4</sub>/day) is dry-matter intake  
213 (DMI), with a strong positive correlation between methane emissions and DMI (Buddle et al.,  
214 2011). The *ad lib* control group had a significantly higher level of DMI (P<0.001), providing a  
215 higher total supply of substrate for methane production in the rumen. Whilst in the respiration  
216 chambers the parasitised lambs consumed 70% of the feed quantity consumed by the *ad lib*  
217 control group. This reduced intake was associated with 20% less methane production in the  
218 parasitised animals. Snap shot measurements of methane output would therefore show parasitism  
219 being associated with a positive environmental impact. However, the methane yield (g CH<sub>4</sub>/kg  
220 DMI) was 33% higher in the parasitised animals compared to the ad-lib control group. The  
221 parasitised lambs also had significantly lower weight gain compared to the controls, and would  
222 require a higher overall feed intake over their lifetime to reach target weight. Whilst worldwide  
223 there is a mixture of sheep management practices i.e. intensively and extensively reared lambs  
224 and a variety of different nutritional environments, parasite induced anorexia is a phenomena  
225 which occurs over all systems where livestock are at risk from gastrointestinal parasites  
226 (Kyriazakis *et al.* 1998; Sutherland & Scott, 2010). Thus the combination of increased methane

227 yield, and higher feed intake per kg product demonstrated in this study has substantial  
228 implications for the impacts of parasitism on emissions from meat production.  
229

230 Low feed intake can be associated with increased methane yield, however, the methane yield  
231 from the parasitised animals was higher than would be expected based solely on their lower  
232 DMI (Hammond et al., 2013). Additionally, despite a significant difference in DMI between the  
233 *ad lib* and restricted fed control groups, there was no significant difference in methane yield  
234 between these groups (Table 1 and Fig. 3). These findings suggest that parasitism has an impact  
235 on methane yield beyond that expected from changes in DMI alone. The extent of bacterial  
236 fermentation is influenced by myriad elements of gastrointestinal physiology and digesta kinetics  
237 (Moraes et al., 2014; Stergiadis et al., 2016). Gastrointestinal nematode infection in small  
238 ruminants can lead to substantial changes in the digestive tract including increased cell turnover,  
239 changes in permeability, changes in pH, altered secretory activities (e.g. mucous production),  
240 and inhibited gastric acid production (Li et al., 2016; Louie et al., 2007). Some of these parasite  
241 induced changes in the gastrointestinal tract will disrupt the intricate interactions between hosts  
242 and their gut microbiome, as the large array of products secreted by gastrointestinal nematodes  
243 impact on growth and metabolism of resident microbial communities (Zaiss & Harris, 2016).  
244 However, we are only now beginning to understand the complexity of microbiota, and the effects  
245 of parasitism on interactions between hosts and their gastrointestinal bacteria remain largely  
246 unexplored (Buddle et al., 2011; Zaiss & Harris, 2016). Thus the effects of parasitism on  
247 microbial survival, proliferation, spatial organisation, and ultimately rate of methanogenesis, are  
248 yet to be understood. Whilst our results identify a novel phenomenon, they do not reveal the  
249 mechanism.

250

251 In this study, weight gain was significantly lower in the parasitised group compared to that in  
252 other groups. This highlights the substantial impact of parasitism on productivity, with  
253 parasitised hosts needing to stay in the system much longer to reach slaughter weight. Attempts  
254 have previously been made to quantify the impacts of parasitism on emissions through exploring  
255 the increased time on pasture, and increased DMI required to reach slaughter weight. Without  
256 accounting for the effects of parasitism on emissions per kg DMI such studies will likely  
257 underestimate the full influence of parasitism on methane production. The parasite driven  
258 increase in methane yield demonstrated in this study, combined with the knowledge that  
259 parasitism decreases production efficiency and increases time to achieve production targets  
260 (Houdijk et al., 2016; Kenyon et al., 2013), demonstrates that parasitism has the potential to have  
261 substantial impacts on livestock methane emissions. In addition to emissions increasing with  
262 parasitism is the concern that parasite intensity is projected to increase under climate change  
263 (Fox et al., 2011, 2012, 2015).

264

265 The potential impact that parasitism has on livestock emissions makes it an attractive target for  
266 mitigation. Parasite control practices (i.e. rearing indoors, clean grazing and *refugia*-based  
267 control strategies), which break the parasite lifecycle, provide an opportunity to sustainably  
268 reduce GHG emissions as it is cost effective, practical, and improves overall production  
269 efficiency. As the increase in ovine meat production is expected to be highest in developing  
270 countries (O'Mara, 2011), with restricted access to improved feeds, feed supplements and  
271 efficiency gains through genetic selection, parasite control offers a viable and accessible way of  
272 reducing emissions.

273

274 This study shows that parasite infections in lambs can lead to a 33% increase in methane yield.

275 Combined with impacts of parasitism on production efficiency, and the subsequent increased

276 time on pasture, there is potential for parasitism to have an extensive impact on GHG emissions.

277 There are international commitments to reduce GHG emissions, and an informed understanding

278 of how production-limiting diseases affect GHG production is vital in developing public policies

279 and combating climate change. As we improve our understanding of how parasitism affects

280 livestock methane emissions we begin to elucidate the true environmental costs of parasitism,

281 and reveal the potential benefits of mitigating emission through controlling infectious disease.

282

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289

### 290 **Declarations of interest**

291 None

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- 370

371 **Figure legends**

372

373 **Figure 1. Indirect measures of parasitism across all treatment groups.**

374 A) Mean faecal egg counts (FEC) (eggs/g faeces) by trial week ( $\pm$ SE), and B) mean pepsinogen  
375 levels ( $\pm$ SE) at three time points, for all three treatment groups of lambs - Ad lib control (*ad lib*  
376 fed), restricted fed control (fed 80% of feed intake of *ad lib* control, to account for parasite  
377 induced anorexia), and parasitised lambs (also *ad lib* fed) .

378

379

380 **Figure 2. Daily mean methane output**

381 Mean methane output in A) grams per hour ( $\pm$ SE), and B) grams per day ( $\pm$ SE), for Ad lib  
382 control (*ad lib* fed), restricted fed control (fed 80% of feed intake of *ad lib* control, to account for  
383 parasite induced anorexia), and parasitised lambs (also *ad lib* fed), averaged across individuals.

384

385

386 **Figure 3. Mean Methane yield**

387 Mean methane yield (grams of methane per kg of dry matter intake) ( $\pm$ SE) for Ad lib control (*ad*  
388 *lib* fed), restricted fed control (fed 80% of feed intake of *ad lib* control, to account for parasite  
389 induced anorexia), and parasitised lambs (also *ad lib* fed).

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392 **Table 1. Performance, feed intake and digestibility**

393 The mean body weight parameters, levels of feed intake, and digestibility values for *ad lib*  
 394 control lambs, restricted fed control lambs, and parasitised lambs, averaged across individuals.

395 Values in rows with different letter superscripts differed significantly ( $P < 0.05$ ).

	Treatments			Standard error	P-value
	<i>Ad lib</i> control	Restricted fed control	Parasitised		
<b>Final BW (kg)</b>	42.6 <sup>a</sup>	37.1 <sup>b</sup>	38.2 <sup>b</sup>	0.8	<0.001
<b>BW gain (g/day) per animal</b>	174 <sup>a</sup>	71 <sup>b</sup>	7 <sup>c</sup>	12.8	<0.001
<b>Daily DMI over trial, per animal (g/day)</b>	1783 <sup>a</sup>	1302 <sup>b</sup>	1396 <sup>c</sup>	28.3	<0.001
<b>Daily DMI per kg BW over trial (g/kg BW/day)</b>	44.6 <sup>a</sup>	34.4 <sup>b</sup>	37.0 <sup>c</sup>	0.98	<0.001
<b>Digestibility Dry Matter (DM, %)</b>	55.4	58.2	58.4	0.01	0.09

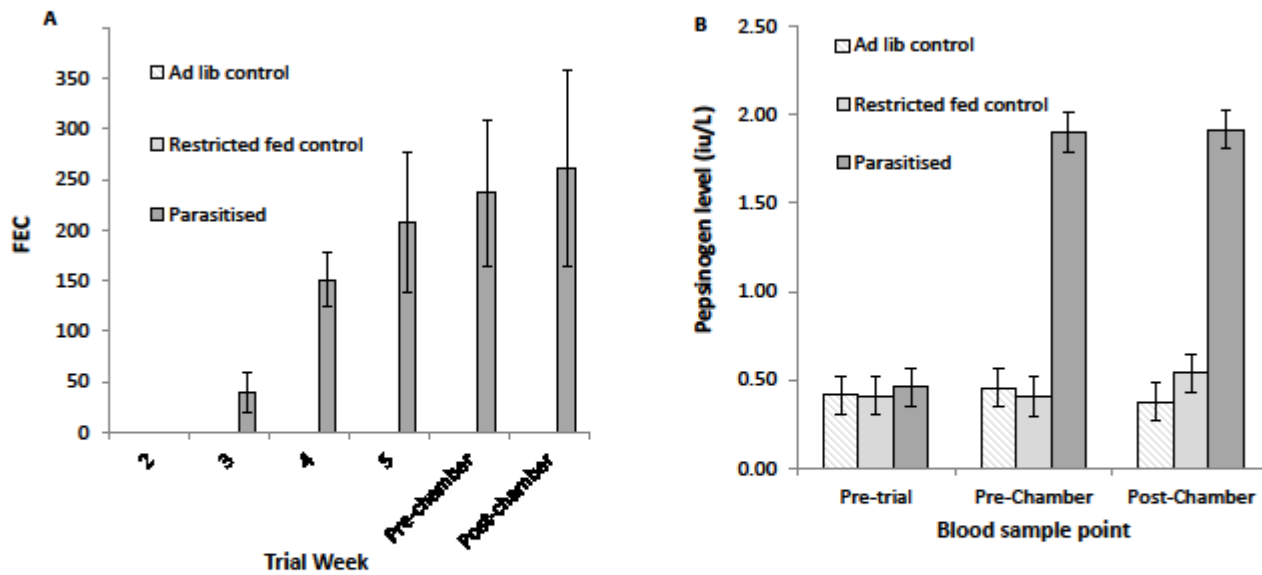


Figure 1.

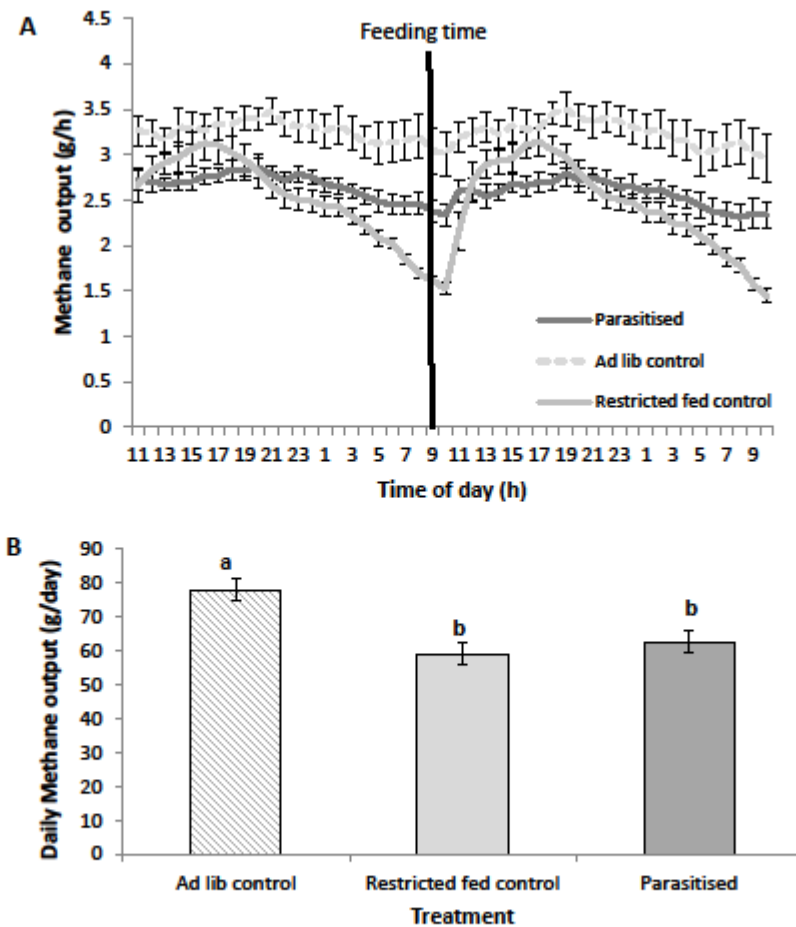


Figure 2.

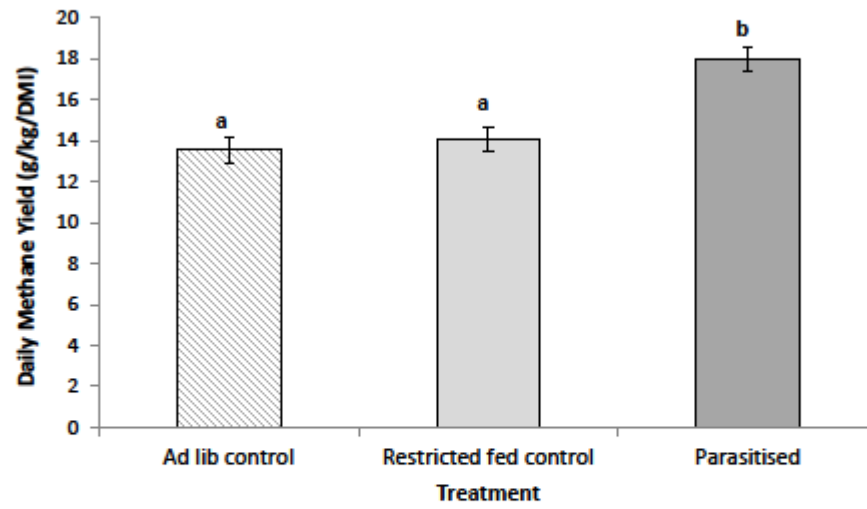


Figure 3.