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Methane emissions from grazing sheep and calves

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Abstract

Methane emission from sheep was measured using a system designed to allow grazing under near natural conditions. In four studies, with periods of continuous measurement of between 4 and 10 days and with animals ranging in age from 7 months to 4.5 years, emission of methane averaged 13.3 g day^{-1} per animal, equivalent to 4.9 kg $year^{-1}$ per animal. Consideration is given to the dry-matter intake of the animals used in these studies and its possible effects on methane production. From the data it is estimated that the total UK sheep population could contribute 247 kt of methane annually to the atmosphere. Diurnal fluctuations in hourly rates of emission were recorded, with methane production increasing during daylight to reach a peak at or near sunset and then declining towards sunrise. This pattern corresponded with diurnal changes in the grazing behaviour of sheep that have been reported elsewhere. In two preliminary studies using calves, methane emissions averaged 74.5 g day^{-1} per animal, with some evidence of a diurnal pattern; emissions were close to theoretical predictions based on animal live weight. © 1997 Elsevier Science B.V.

Keywords: Methane; Sheep; Calves; Grazing behaviour; Diurnal patterns

1. Introduction

Methane (CH_4) has been estimated to contribute about 18% of the overall global warming potential, second only to CO_2, and its concentration has increased over recent years at rates of between 0.5% and 1.1% per year (Bouwman, 1990; Rodhe, 1990; Steele et al., 1992). Recent estimates suggest an annual global emission of 540 Tg, of which 15% is derived largely from domesticated animals via enteric fermentation (Bouwman, 1990; Crutzen, 1991; IPPC, 1992). In the UK, 37% of the annual emission of CH_4, estimated to be 4.2 Tg (Watt Committee on Energy, 1993), has been attributed to agriculture, where the main source is ruminant animals. To be able to construct accurate budgets and assess opportunities for reduction there is a need for reliable estimates of CH_4 production by ruminants, particularly under the conditions of normal farming practice and husbandry. Several studies have used animals in controlled conditions, usually in respiratory chambers, to assess the effect of diet and intake on CH_4 production (Kirchgessner et al., 1991; Leng, 1991; Moss and Givens, 1995). More recently attention has been given to losses from livestock housed under normal conditions throughout, or for some part of, the production process (Seedorf, 1996; Sneath, 1996). Although one other study has assessed the amounts of CH_4 released by cattle within a grazing system

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(Denmead, 1994) there are few other data relating to this important component of production.

Previous studies at North Wyke have measured CH_4 emissions from sheep grazing under near natural conditions (Lockyer and Jarvis, 1995). The work reported here, a continuation of those studies, was aimed at measuring CH_4 emission from sheep over longer grazing periods. In addition, the results from two preliminary studies with calves are included.

2. Materials and methods

2.1. Apparatus

The measurement system used in the studies reported here has been fully described in an earlier paper (Lockyer and Jarvis, 1995). Briefly, it consisted of: (i) a large polythene tunnel, (ii) two small wind-tunnels used to blow air into, and draw air from, the larger tunnel, (iii) apparatus to measure and record the concentration of CH_4 in air entering and leaving the tunnel and (iv) apparatus to monitor and record airspeeds and temperatures.

The large tunnel was a commercial, polythene-clad greenhouse (hereafter referred to as a polytunnel) modified to make the entire structure portable; it was 4.3 m wide and 9.9 m long with a maximum height at the ridge of 2.1 m giving an approximate volume of 66 m^3. Its framework, formed from a series of steel hoops attached to a rectangular base, was covered with white polythene sheeting. At both ends of the tunnel, polythene sheeting was drawn down to form funnel-like connections to each of the small wind-tunnels.

The design and operation of the small wind-tunnels have been described by Lockyer (1984). Each tunnel consisted of a steel duct, 1.5 m long and 0.4 m i.d., housing a variable speed co-axial fan and a vane anemometer. Air flow through each tunnel could be controlled at rates of up to 1.0 $m^3\ s^{-1}$. The output from each anemometer was recorded by a data logger to provide an integrated measurement of airspeed from which the volume flow of air through the tunnel could be calculated.

Methane concentrations in air entering and leaving the polytunnel were measured through an automatic sampling and injection system connected to a gas chromatograph (GC) fitted with a Flame Ionisation Detector (FID). Samples (2.0 ml) were taken every 2 min, with alternate samples being drawn from the inlet and outlet of the tunnel, and injected onto the GC column; the output from the FID was scanned continuously by a data logger which was programmed to detect, integrate and record each CH_4 peak.

Psychrometers, mounted inside and outside the polytunnel and connected to a data logger, enabled air temperature and humidity to be monitored and the measurements recorded every 10 min throughout each study.

2.2. The measurement of methane emission

Six studies, details of which are given in Table 1, were carried out at the IGER farm at North Wyke in

Table 1
Details of each grazing study

Study no.	Animals	Age (months)	Average weight (kg)	Measurement period From	To	Airflow ($m^3\ s^{-1}$)	Sward dry-matter on offer (g m^{-2})
1	2 Shearling ewes (Scottish half-bred × Border Leicester)	18	68	20 Sep. 94 15:00 BST	26 Sep. 94 15:00 BST	0.29	490
2	2 Ewe lambs	7	33	11 Oct. 94 11:25 BST	21 Oct. 94 09:30 BST	0.27	455
3	2 Ewe lambs	8	35	15 Nov. 94 11:20 GMT	21 Nov. 94 11:30 GMT	0.34	520
4	2 Ewes (Scottish half-bred)	54	75	16 Oct. 95 15:00 BST	20 Oct. 95 15:00 BST	0.35	430
5	2 Calves (Friesian × Hereford)	8	150	11 Jul. 95 11:15 BST	12 Jul. 95 11:15 BST	0.54	205
6	2 Calves (Friesian × Hereford)	10	190	06 Sep. 95 15:50 BST	08 Sep. 95 16:20 BST	0.85	405

SW England during the period September 1994 to September 1995. For each study the polytunnel was positioned over a fresh area of sward within a paddock consisting predominantly of perennial ryegrass (*Lolium perenne* L.). At the start of each study an estimate was made of the amount of herbage on offer; two 0.4 m × 0.4 m quadrats were positioned randomly and the herbage within the areas so defined was cut at ground level, dried overnight at 100°C and weighed. The animals were held in an enclosure of metal hurdles erected within the polytunnel and had access to a grazing area of approximately 33 m^2; they were provided with a drinking trough supplied automatically with fresh water.

In each study the measurement of CH_4 concentration began 2 h before the animals were moved into the polytunnel and continued for 1–2 h after they were removed.

3. Results and discussion

3.1. Methane emission from grazing sheep

In the earlier studies (Lockyer and Jarvis, 1995), groups of 5 or 12 ewes grazed swards enclosed within the polytunnel, allowing only relatively short periods of between 19 and 51 h during which CH_4 emission was measured. At such high stocking densities the swards were sometimes poorly grazed because of the fouling and treading of the herbage. Subsequently, and in the four studies reported here, only two animals were used, enabling uninterrupted measurements to be made over periods of from 4 to 10 days.

Frequent observation throughout the daylight hours was aimed at monitoring the well-being of the animals and was not intended as an assessment of grazing behaviour. At the lower stocking density used in these studies the swards were not fouled and were well grazed to leave a uniform stubble; the animals settled quickly and in every respect appeared to behave normally. At no time was it necessary to remove the animals from the polytunnel because of excessively high temperatures.

Table 2 shows the daily amounts of CH_4 emitted per animal during each of the four studies. Emission rates were highest on the first day of each study, with ewes producing almost double the amount of CH_4 produced by lambs. Thereafter the emission rate tended to fall from day to day, although in Study 2 it remained at about the same level on days 3–7.

Confining sheep within the polytunnel was more akin to rotational or paddock grazing than to continuous stocking; with two animals, the stocking density was equivalent to about 600 head ha^{-1} compared with 10 to 12 head ha^{-1} for continuous stock-

Table 2
Summary of methane emissions from sheep and calves

Study no.	Methane[a] emission per animal, (g day^{-1})										
	Day no.										Mean
	1	2	3	4	5	6	7	8	9	10	
Sheep											
1	25.6	16.4	13.6	13.1	12.0	10.7					15.2
2	17.9	16.8	12.4	11.8	15.1	12.6	11.2	8.3	9.6	7.1	12.3
3	15.7	9.7	8.3	5.8	4.4	3.8					8.0
4	29.0	21.5	16.5	16.6							20.9
Weighted mean											13.3
Calves											
5	77.8										77.8
6	82.6	63.2									72.9
Weighted mean											74.5

[a]Here, and in the text, conversion from volumetric units to mass assumes a temperature of 20°C but makes no adjustment for changes in atmospheric pressure i.e., 1.0 g CH_4 = 1.5 l gas.

ing. Penning et al. (1994) showed that sheep under rotational grazing changed their ingestive behaviour in response to a decline in the ratio of leaf to stem in the sward; intake fell as green leaf mass was reduced below about 1500 kg ha^{-1}. Other workers (Allden and Whittaker, 1970; Jamieson and Hodgson, 1979) have reported intake maxima by sheep at 2000–3000 kg ha^{-1} DM. It is reasonable to assume, therefore, that at the start of each of the present studies, intake was not limited by the DM on offer (Table 1) and CH_4 production, at about 25–30 g day^{-1} for the ewes and 15–18 g day^{-1} for the lambs, was approaching a maximum for these particular animals grazing one particular sward. Thereafter, intake would have fallen with the decline in leaf material as grazing progressed. Intake was not measured in the present studies. However, if it is assumed that during each study no more than 33% of the herbage on offer was actually consumed by the animals, daily intake can be estimated to have averaged 0.44 kg day^{-1} per animal. Clearly, DM intakes in these studies were low, but within the range of 0.31 kg to 1.65 kg day^{-1} per animal given for growing sheep (ARC, 1980). Penning et al. (1995) reported DM intakes of 1.50–1.89 kg day^{-1} by both dry and lactating ewes grazing grass in the autumn and 2.5 kg day^{-1} per animal by lactating ewes grazing grass during spring and summer; swards were managed to maintain a constant height and would not have been expected to have restricted intake. Moss and Givens (1995) have found CH_4 emission by sheep to be significantly related to DM intake in open-circuit respiration chambers when fed with grass silage supplemented with a range of concentrates; the relationship, while not necessarily applicable to a diet of grazed grass, would predict CH_4 production over the wide range of intakes given above at between 7.0 g and 59.0 g day^{-1} per animal. The same relationship would predict, for the present studies, a CH_4 production of about 10.0 g day^{-1} per animal, close to the measured average of 13.3 g day^{-1} per animal, given the imprecise estimate of DM intake.

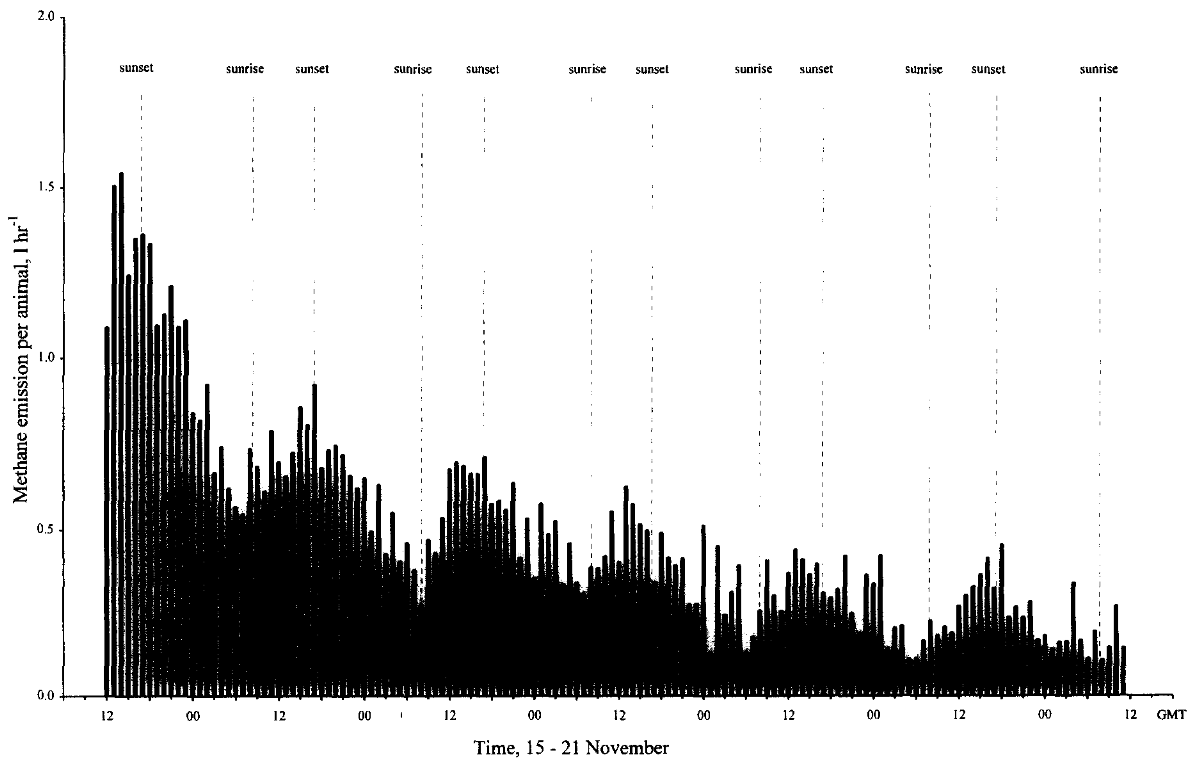

Fig. 1. Emission of methane by grazing sheep during each hour of Study 3.

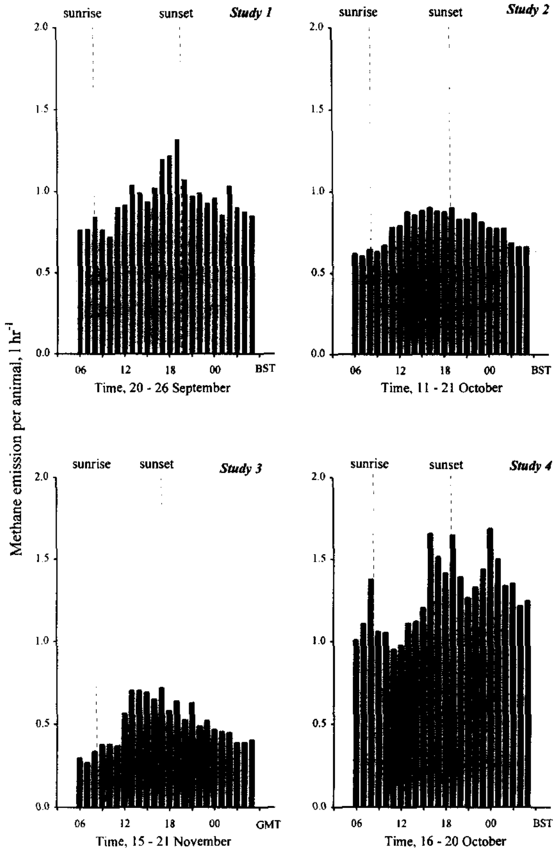

Fig. 2. Emission of methane by grazing sheep averaged over the same hourly period in each day—Studies 1–4.

By extending the periods of measurement in these studies it was possible to seek patterns in the emission of CH_4 which might reflect grazing behaviour. Fig. 1 shows the volume of CH_4 emitted during each hour through the 6 days of Study 3. Similar patterns of emission were found in the other studies and these are summarised in Fig. 2, where emissions in consecutive periods of 1 h have been averaged for the corresponding periods in each day.

Fig. 1 shows a clear pattern throughout Study 3, with CH_4 emission reaching a peak at or around sunset and then falling through the night to a minimum at dawn. This same pattern is also evident for the mean hourly values shown in Fig. 2, though perhaps less convincingly in Study 4. Penning et al. (1991), studying the ingestive behaviour of sheep grazing grass, concluded that 72% of grazing occurred during daylight and that sheep concentrated their grazing in the 4 h period immediately before sunset; in mid-October 36% of the daily total of time spent grazing was between 15:00–19:00 h BST. Champion et al. (1994) confirmed this daily pattern of grazing behaviour; they recorded a large peak in eating activity just before sunset (16:00 h GMT in February/March) giving a strong 24 h periodicity and suggested further peaks of activity at 8 h intervals i.e., at 08:00 h and 24:00 h GMT. Only in one of the studies reported here (Study 4) is there some evidence of these other peaks as demonstrated by CH_4 emission.

Grazing behaviour was not assessed in the present studies. However, the pattern of CH_4 emission is certainly compatible with the grazing behaviour described above; from sunrise, as grazing activity increased so did CH_4 emission, with the accumulation of ingesta in the rumen. Later, after sunset, grazing gave way to rumination or idling and emissions fell as the content of the rumen was reduced.

The overall mean emission rate of 13.3 g day^{-1} per animal, measured for sheep differing widely in age and live weight, is close to the average of 14.0 g day^{-1} per animal found in the earlier studies (Lockyer and Jarvis, 1995) with ewes aged either 14–15 months or 24–30 months. The highest daily mean rates of CH_4 emission were 29.0 g day^{-1} per ewe and 17.9 g day^{-1} per lamb measured on the first day of the relevant study. However, after making a retrospective estimate of the mean DM intake of the animals during these studies and calculating their energy requirement by the methods given in AFRC (1993), it seems probable that only in Study 3 was the estimated mean daily DM intake adequate for maintenance throughout the study period. To use the overall mean, therefore, in any wider assessment of emission, would be to underestimate this important source of CH_4. If it is assumed that, during the first two days of each study, intake was not limited by the amount of herbage on offer then the average emissions of CH_4 during that period—23.1 g day^{-1} for the ewes and 15.0 g day^{-1} for the lambs—may be more realistic.

In June 1994 the total UK breeding sheep flock numbered 20.5 million animals, with other sheep and rams taking the total to about 22.3 million animals (MLC, 1995). At the measured mean rate of CH_4 emission for ewes this would amount to 188 kt per year. At the same census there were 21.5 million sheep and lambs under 1 year old; applying to this figure the mean rate of CH_4 emission for lambs, and assuming that these animals are present for only half the year, would bring the annual emissions of CH_4 up to 247 kt. This is lower than some earlier estimates of 330, 384 and 275 kt year^{-1} by Jarvis (1991), Moss (1993) and the Watt Committee on Energy (1993), respectively.

These studies have shown that CH_4 emissions from sheep appear to be linked to diurnal patterns of grazing behaviour and, by implication, to changing levels of DM intake. It would be useful to confirm these relationships in further studies with animals having much higher nutritional demands and hence higher DM intakes than the lambs and dry ewes studied here.

It is clear that attempts to refine estimates of the contribution made by sheep to current budgets of atmospheric CH_4 will need to take account of the various classes of animals within the national flock, their different nutritional requirements and the availability of feed and forages. Measurements of CH_4 production, or indeed, DM intake, made over short periods are unlikely to provide data that reflect the diurnal and seasonal changes in grazing behaviour and diet met with in farming practice, in a variety of upland and lowland environments.

3.2. Methane emission from grazing calves

The two studies summarised in Table 1 are first attempts at assessing CH_4 emissions from cattle using the system hitherto employed with sheep. The same two animals were used in both studies; they were docile, accustomed to being handled and settled immediately to grazing when introduced into the polytunnel. The available herbage was well grazed by the calves but the amount on offer limited the measurement periods to 1 and 2 days. Fig. 3 shows the amounts of CH_4 emitted in each hour of both studies. As with the sheep, there appeared to be a diurnal pattern of emission, with rates increasing during daylight and falling after sunset. In his study with cattle, Denmead (1994) found peaks of CH_4 emission during periods of rumination and troughs during periods of grazing, the cycle being repeated every 3 h; no such short term cycles could be established in the present data.

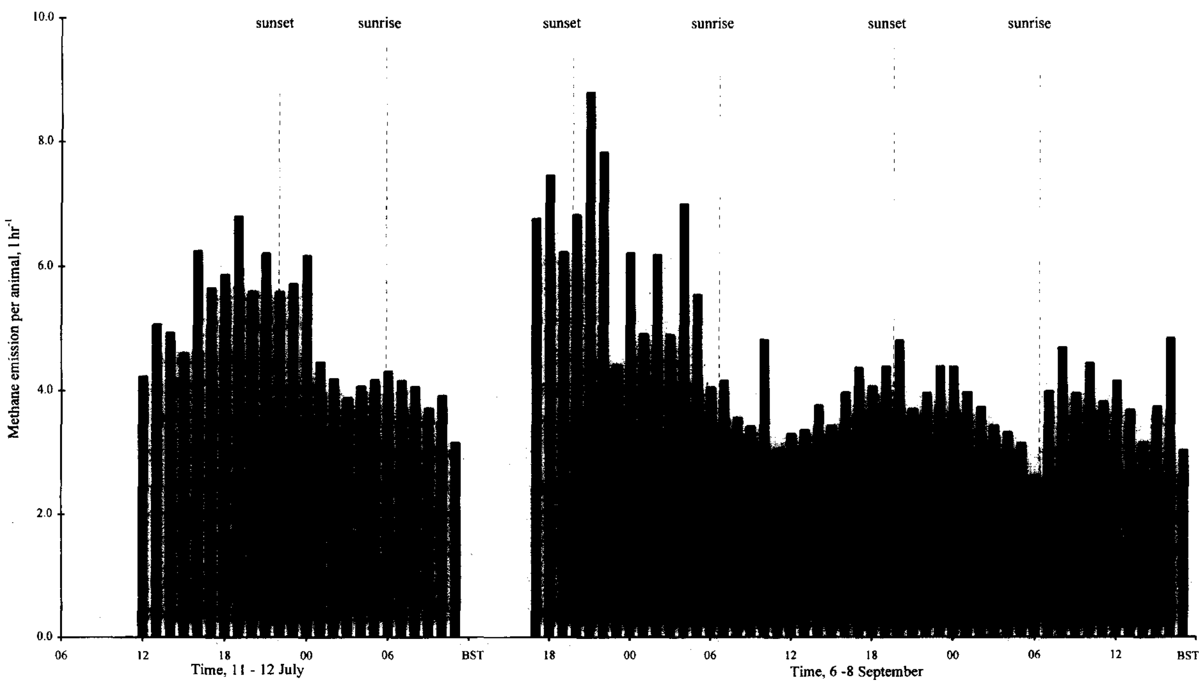

Fig. 3. Emission of methane by grazing calves during each hour of Studies 5 and 6.

Crutzen et al. (1986) made a theoretical estimate of CH_4 emission by cattle of 10.0 g hr^{-1} per 500 kg of live weight (LW). The average rate of emission per calf in the present studies was 74.5 g day^{-1} or 8.2 g hr^{-1} per 500 kg LW, close to the value given above and within the values of 6.7 and 12.2 g hr^{-1} per 500 kg LW given by Seedorf (1996) for housed beef cattle and cows, respectively.

The calves used in this study were probably the largest animals that the present system can accommodate. Mature beef or dairy cattle could easily be contained within a larger polytunnel but there would be implications for stocking density and DM intake. A more portable system would allow frequent moves to fresh areas of sward during a single grazing period, enabling realistic levels of DM intake to be maintained throughout.

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