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THE MEASUREMENT OF METHANE LOSSES FROM GRAZING ANIMALS

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Abstract

A detailed description is given of the construction, operation and calibration of a system designed to measure methane emissions from sheep grazing in the field under as near natural conditions as possible. Results from four preliminary studies show that emission of methane averaged 14 g day^{-1} per animal, equivalent to 5.1 kg year^{-1} per animal. These rates, although lower than some estimates, confirm that methane emission from sheep forms a significant proportion of the total methane emissions currently attributed to UK agriculture.

Keywords: Methane, sheep, grazing, measurement system.

INTRODUCTION

Atmospheric methane (CH_4) concentration has been increasing significantly over recent years at rates of 0·5% to 1·1% per year (Bouwman, 1990; Steele *et al.*, 1992). Methane is a radiatively active gas with 25 times more infrared absorbing capability per molecule than CO_2 and acts as a major source of potential global warming (Rodhe, 1990): it is estimated that CH_4 now contributes about 18% to global warming potential, second only to CO_2. Estimates have been made of CH_4 sources, and their strengths, in order to provide information on global emissions (Bouwman, 1990; Crutzen, 1991; IPCC, 1992; Moss, 1993). These suggest that of an annual global emission of 540 Tg approximately 80 Tg, i.e. 15% of the total, is derived from enteric fermentation and that this is largely from domesticated ruminants. Recent estimates of CH_4 emissions from known UK sources (Watt Committee on Energy, 1993) indicate that agriculture, almost entirely through animal production systems, is responsible for 37% of total CH_4 emissions.

The rumen acts as a fermentation vessel supporting large populations of microbial organisms which degrade plant materials and, in so doing, release CH_4. Because of the significance of this release, in terms of the utilisation of metabolizable energy, CH_4 production has been measured directly or estimated through an understanding of energy balances (Moe & Tyrell, 1979; Kirchgessner *et al.*, 1991; Leng, 1991; Moss, 1993; Shibita, 1994). In all cases, these studies used animals housed in controlled conditions receiving defined diets with the aim of assessing the effects of dietary quality and intake on CH_4 release and energy loss.

Data from this type of study have formed the basis of current estimates of national and global CH_4 budgets. However, most ruminant production systems involve grazing, a situation in which interactions between soil, plant and animal may influence net CH_4 emission. Thus not only will there be direct effects of grazing patterns and dietary quality on CH_4 production in the rumen, but soil (as potential sink or source of CH_4) and excreta (potential source) may exert significant effects. Whilst estimates of some of these effects have been made (Bakken *et al.*, 1994; Jarvis & Pain, 1994; Jarvis & Moss, 1994) there has been only one recent attempt to provide an integrated measurement of net CH_4 release from a grazing system (Denmead, 1994). If accurate budgets of CH_4 emission are to be constructed and used in the modelling of global warming, it is essential that realistic, confident assessments of emissions of CH_4 in the field are made. The aim of the work reported here was to establish a system for making direct measurements of CH_4 emission from grazing ruminants under near natural conditions. We also present results which provide a preliminary basis for assessing the contribution of grazing sheep to the emission of CH_4 in the UK.

MATERIAL AND METHODS

Apparatus

The system developed for use in these studies consisted of: (i) a large polythene tunnel, (ii) two small wind-tunnels, one to blow air into, the other to draw air from, the larger tunnel, (iii) equipment to measure and record the concentration of CH_4 in air and (iv) equipment to monitor and record temperatures and airspeeds.

The polythene tunnel

The tunnel was a commercial, polythene-clad greenhouse (Highlande 14, Clovis Lande Associates Ltd) modified to make the entire structure portable. The tunnel was 4·27 m wide, 9·91 m long with a maximum height at the ridge of 2·06 m, giving an approximate volume of 66 m^3. All supporting hoops were attached to a base-frame, rather than to anchorages driven into the ground, and the polythene cover was fixed to an aluminium strip attached to the bottoms of the hoops along both sides of the tunnel. Steel plates were bolted to the base-frame at each corner and at two equally spaced positions along the length of the frame. After positioning the tunnel, two steel pins were driven through holes in the plates to anchor the whole structure to the ground. The framework was covered with white polythene sheeting (720G, 180 μm). A flap of polythene about 0·5 m wide was left along each side of the tunnel on which sand-bags were placed to help hold down the tunnel and to limit the inflow of air between the base of the tunnel and the ground. At both ends of the tunnel, polythene sheeting was fixed to the hoops and drawn down to form funnel-like connections to each of the small wind-tunnels.

Wind-tunnels

The design and operation of the wind-tunnels have been described in detail by Lockyer (1984). Briefly, each tunnel consists of a steel duct, approximately 1·5 m long and 0·4 m i.d., housing a variable speed co-axial fan and a vane anemometer head. Air flow through each tunnel can be controlled at rates of up to 0·9 $m^3 s^{-1}$.

Monitoring equipment

The equipment used to monitor temperature and humidity inside and outside the polytunnel, airspeed in the two wind-tunnels and CH_4 concentrations in the air entering and leaving the polytunnel, is shown schematically in Fig. 1.

Temperature and humidity: Two psychrometers (A1, A2), each containing thermistors to measure dry-bulb and wet-bulb temperatures, were connected to a data logger (B1). One psychrometer (A1) was mounted inside the polytunnel (C), the other (A2) being positioned outside to measure ambient conditions. Both psychrometers were connected to a power supply which drove a small integral fan to provide the necessary aspiration of the wet-bulb thermistor. The fan was activated by a signal from the logger 1 min before the resistances were recorded by the data logger.

Airspeed: The vane anemometer heads (D1, D2) were connected to a switch (E) which allowed each output to be selected for display on an electronic anemometer (F) without affecting the signal that was fed continuously to the data logger (B1); the frequency of the signal, which is linearly related to airspeed, was used to drive pulse counters. The total count over the period between scans (10 min) was effectively an integrated measurement of airspeed from which the volume flow of air was calculated.

Methane concentration: Methane concentrations in sampled air were measured using a gas chromatograph (GC) (G) fitted with a stainless steel column (2 mm i.d; 5·5 m long) filled with Porapak 'Q' and operated at a temperature of 50°C and with a carrier gas (helium)

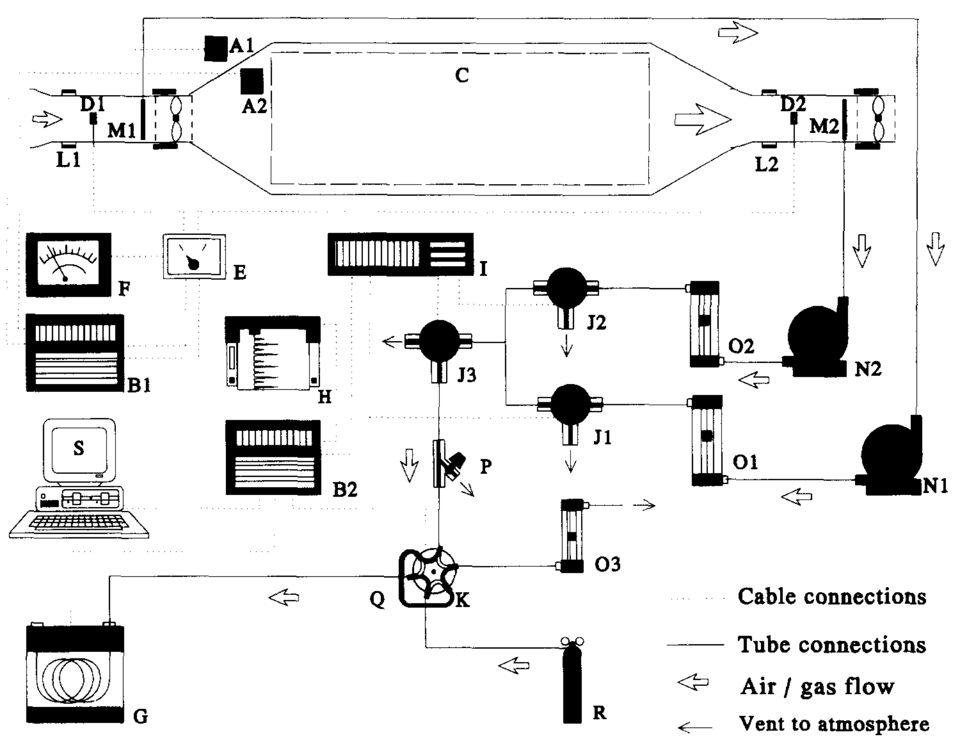

Fig. 1. Schematic diagram of methane measuring system. Arrows indicate direction of air or gas flow. A(1–2), psychrometers (Delta-T Devices, Burwell, Cambs.); B1, data logger (Delta-T Devices, Burwell, Cambs.); B2, data logger (Model 21X micrologger, Campbell Scientific Ltd, Loughborough, Leics); C, polytunnel (Highlande 14, Clovis Lande Associates Ltd, Tonbridge, Kent); D(1–2), vane anemometer heads connected through E, a two-position switch to F, an electronic anemometer (EDRA-5, Airflow Developments Ltd, High Wycombe, Bucks.); G, Gas chromatograph (Pye Unicam, Cambridge, Cambs.); H, chart recorder; I, sampling unit controlling three-way solenoid operated valves J(1–3); K, automatic sample injector; L(1–2), wind-tunnels; M(1–2), air sampling device; N(1–2), air pumps (Type 361, Charles Austin Pumps Ltd, Weybridge, Surrey); O(1–3), flow meters (G. A. Platon Ltd, Basingstoke, Hants.); P, bleed valve; Q, injection loop; R, carrier gas supply — helium; S, portable computer.

flow of 34·0 ml min^{-1}. The output from the Flame Ionisation Detector (FID) was fed continuously to a chart recorder (H) and to a second data logger (B2). This data logger was at the centre of an automatic gas sampling and injection system. It was programmed to: (i) control, through a sampling unit (I) and solenoid valves (J1–3), the delivery of air to the automatic sample injector (K) fitted to the GC, (ii) control the automatic sample injector (K) and (iii) monitor the output (mV) of the FID.

Operation

With the polytunnel secured over the chosen area of sward, the small wind-tunnels (L1, L2) were attached to both openings, one at the inlet blowing air into, and the other at the outlet drawing air from, the polytunnel. Whatever rate of airflow was chosen, the inlet flow was always adjusted to be less than the outlet flow so that a slight negative pressure was maintained and the difference in flow was made up by leakage of air into the polytunnel. The measured volume of air flowing through the outlet, therefore, represented the total flow through the polytunnel. Emission of CH_4 was calculated as the product of the total flow of air during each 4 min period and the difference between CH_4 concentrations in the air entering and leaving the polytunnel during that period.

Both small wind-tunnels were fitted with a device (M1, M2) designed to improve the sampling of the air passing through the duct. It consisted of six tubes radiating symmetrically from a central hub; each tube had three holes, of different diameters and spacings with the aim of equalizing air flow through each hole when suction was applied to the central hub.

To monitor CH_4 concentration, air was drawn continuously, at 8.0 litre min^{-1} from these two sampling devices (M1, M2), by separate diaphragm pumps (N1, N2) and pumped, via flow-meters (O1, O2), to 3-way solenoid valves (J1, J2) which connected each sampling line to a common manifold. Nylon tubing, of 4 mm i.d., was used throughout for all sample delivery lines.

Only one of the sampling lines was connected to the manifold at any one time; when the appropriate solenoid valve was switched on by the sampling unit (I), air entered the manifold but was otherwise vented to waste. From the manifold the air passed through another 3-way solenoid valve (J3) and then, via a bleed (P) which provided control of the flow of air, to the two-position valve contained in the automatic sample injector (K). In the first position, this valve directed the flow of air through a 2.0 ml loop (Q) and from there to atmosphere through a flow meter (O3). On a command from the data logger (B2), the solenoid valve (J3) was activated to stop the supply of air from the manifold and allow the pressure in the delivery line to fall to atmospheric. A second command from the logger activated the automatic sample injector to switch to its second position, connecting the sampling loop into the carrier gas supply line from cylinder (R), which carried the air sample to the GC column.

Both data loggers were connected to a portable PC (S), which was used to prepare and transfer logging programs and to collect data stored in the loggers. The PC was also used to monitor the operation of both loggers and the instantaneous readings from each sensor.

The system allowed a new sample of air to be injected onto the GC column every two minutes, with alternate samples being drawn from the inlet and outlet of the polytunnel. The output from the FID was scanned continuously by the data logger (B2) at 0·2 s intervals. The logger was programmed to detect and then to measure the CH_4 peak by summing all the mV readings made whilst the FID response remained above a base-line value. The GC was calibrated by injecting 2·0 ml samples of CH_4 standards prepared in helium, and calculating a standard curve by the regression of 'mV sum' on concentration.

Initial studies

The measurement of CH_4

A cylinder of compressed air was used to supply a continuous flow of air, at a stable CH_4 concentration, to the automatic sample injector. Samples of air were injected onto the GC column every 2 min for 44 h and an assessment made of the reproducibility and precision of the CH_4 measurements. In another test the output from the FID was logged every 0·2 s over several measurement cycles and the data used to estimate the error of a mean 'base-line' value.

The recovery of added CH_4

Several tests were made to check the ability of the measurement system to make a quantitative recovery of known CH_4 additions. Pure CH_4 was bled into the polytunnel through a precision gas meter, over different lengths of time and at different flow rates, and inlet and outlet concentrations were measured continuously.

Methane emission from grazing sheep

Four separate studies were carried out at the Institute farm at North Wyke in SW England during the period May – October 1993 with the polytunnel positioned over a sward consisting predominantly of perennial ryegrass (*Lolium perenne* L.). The animals were held in an enclosure of metal hurdles erected within the polytunnel and were provided with a drinking trough supplied automatically with fresh water. Airflow through the polytunnel was usually set at 0·25 m^3 s^{-1}; any departure from that setting is shown in the summary of each study given below. Air temperature and humidity within the polytunnel were monitored throughout each study. Only during Study 3 did it prove necessary to remove the animals from the polytunnel because of excessively high temperatures.

An estimate was made of the amount of herbage on offer beneath the polytunnels at the start of each study. Two 0·5 m × 0·5 m quadrats were positioned randomly and the herbage within the areas so defined was cut at ground level, dried at 100°C and weighed. Details of each study are as follows.

Grazing study 1:

Animals: 12 ewes, 14 months old, of average weight 44·5 kg.

Measurement period (BST): 1500 h 18 May – 1030 h 19 May.

Airflow: 0·5 m^3 s^{-1} throughout.

Management: animals had been grazing similar herbage in an adjacent paddock for several days before being moved into the polytunnel.

Polytunnel placement: 30 days before starting the study.

Sward dry-matter on offer: 350 g m^{-2}.

Grazing study 2:

Animals: 5 ewes, 15 months old, from the same group that was used in Study 1.

Measurement periods (BST):

(1) 0940 h – 1650 h 15 June;

(2) 1650 h 15 June – 1140 h 16 June;

(3) 1140 h 16 June – 1200 h 17 June.

Airflow: 0·25 m^3 s^{-1} but increased to 0·5 m^3 s^{-1} for the period 1200 h – 1650 15 June.

Management: animals had been in an adjacent paddock since Study 1; the area under the polytunnel was divided into three and a third used for each of the above periods.

Polytunnel placement: a new area of sward 7 days before starting the study.

Sward dry-matter on offer: 300 g m^{-2}.

Grazing study 3:

Animals: the same 5 ewes that were used in Study 2.

Measurement periods (BST):

(1) 1645 h 17 August – 1145 h 18 August;

(2) 1010 h 20 August – 1010 h 21 August.

Airflow: 0·25 m^3 s^{-1} but increased to 0·7 m^3 s^{-1} for the period 1400 h – 1630 h 20 August.

Management: animals were transported from a neighbouring field and held in a trailer for about 3 h before the study began, to encourage them to graze. Because of high temperatures (>30°C) in the polytunnel the animals were removed and held in an adjacent paddock during the time between the two measurement periods. There was no partitioning of the area beneath the polytunnel in this study.

Polytunnel placement: a new area of sward 5 h before starting the study.

Sward dry-matter on offer: 290 g m^{-2}.

Grazing study 4:

Animals: 5 ewes, 2–2·5 years old and not previously used in these studies.

Measurement period (GMT): 1400 h 28 October – 1530 h 29 October.

Airflow: 0·25 m^{-3} s^{-1} throughout.

Management: Animals were held in an adjacent paddock for 24 h before the study began.

Polytunnel placement: a new area of sward 24 h before starting the study.

Sward dry-matter on offer: 260 g m^{-2}.

In each study, measurement of CH_4 concentration and environmental variables started 2 h before the sheep were introduced and continued for 1–2 h after the grazing period was completed.

RESULTS AND DISCUSSION

Measurement of CH_4

With the output from the FID adjusted to a nominal 'base-line' value of 0·0 mV (SE_{mean} = ± 0·0005 mV) the CH_4 peak, from 2·0 ml samples of air containing CH_4 at about ambient concentration, produced a maximum response of 5·034 ± 0·0008 mV. Continuous measurement of this stable concentration of CH_4 gave a mean of 1·941 ± 0·00037 vpm (SE_{diff} = ± 0·00053 vpm). During the four studies with sheep in the polytunnel, the inlet (ambient) concentration of CH_4 ranged from 1·67 to 2·38 vpm and the outlet concentration ranged from 2·28 to 22·1 vpm. In every study the minimum outlet

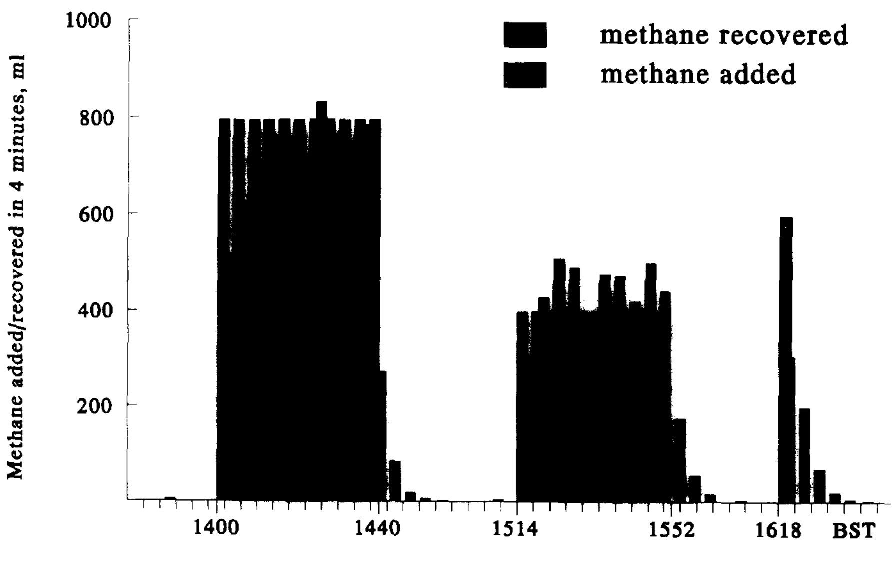

Fig. 2. Recovery of methane added to polytunnel during three experimental periods.

Table 1. Methane measured leaving the polytunnel compared with amount of methane added

Date	Time (h BST) methane added*		Period of addition	Airflow through polytunnel	Total methane added	Estimate of methane added	Recovery
	from	to	min	$m^3 s^{-1}$	litre	litre	%
7 July							
	12·26	14·36	120	0·25	8·198	6·749	82·3
	15·06	15·26	20	0·25	3·974	3·408	85·8
	16·34	10·16	1062	0·25	71·876	76·792	106·8
	Total				84·048	86·949	103·5
19–20 July							
	12·31	12·36	5	0·25	0·343	0·394	114·9
	14·01	14·06	5	0.25	0·994	0·911	91·6
	14·36	15·10	34	0·25	6·756	7·456	110·4
	15·44	16·22	38	1·25	2·603	2·880	110·6
	Total				10·696	11·641	108·8
26 July							
	14·00	14·40	40	0·25	7·948	7·522	94·6
	15·14	15·52	20 (10 × 2 min)	0·25	3·974	4·679	117·7
	16·18	16·21	3	0·25	0·596	0·598	100·3
	Total				12·518	12·799	102·2

* Methane measurement was continuous.

concentration exceeded the maximum inlet concentration by more than 10%.

Recovery of added methane

The results from the tests in which CH_4 was added to the polytunnel and estimates then made, using the complete measurement system, of the amounts leaving the outlet indicated that a very good recovery was achieved (Table 1) on each occasion. Figure 2 shows in detail, for just one of the tests, the volume of CH_4 recovered in each 4-min period compared with the theoretical addition.

The percentage recovery of the added CH_4 ranged from 82·3% to 117·7% in individual periods with an overall average of 104%. Accuracies of ± 5% specified by the manufacturers for the flow-meters and the anemometers would alone give calculated recoveries in the range 90·5 – 110·5% regardless of any other experimental error. The detail shown (Fig. 2) over one of the test periods of the volume of CH_4 recovered in each 4 min-period indicates that a lag of perhaps 15–20 min was apparent before the volume of the CH_4 recovered reached the level of addition. Once the CH_4 supply was stopped it took a similar period for the residual gas to be exhausted. From these studies it was concluded that the system could be used to provide quantitative estimates of the net CH_4 released within the polytunnel.

Methane emission from grazing sheep

The system provided the opportunity to monitor CH_4 emission during successive hours in each study (Fig. 3). Methane concentration in the air leaving the polytunnel showed an immediate increase when the animals were introduced. At this stage the animals were not grazing or ruminating but were quite clearly emitting CH_4 at a high rate, even before settling to anything approaching feeding patterns. In each study, the highest rates of emission were measured in the first few hours after introduction, even though this was not always a period when grazing was observed. It is possible that these high rates were a physiological response to the disturbance caused by the transfer into the polytunnel. However, more recent studies (Lockyer, 1994, unpublished data) over much longer periods have shown a consistent diurnal pattern of emission. The hourly rates measured in the current study are well within the range measured in these later studies and have therefore been included in the overall calculation of the daily rates of emission.

The prime aim in developing this system was to have the ability to monitor CH_4 emission from animals behaving as normally as possible under near natural conditions. Observation of the animals during each study was not intended as a quantitative assessment of time spent on any particular activity; rather, the aim was to monitor the well-being of the animals and to try to assess whether their behaviour could still be regarded as normal under these conditions. Such an observation, although frequent, was limited to the daylight hours.

In Study 1 the animals settled down very quickly and were grazing within the first hour and some were resting and ruminating within 2 h. In contrast, in Study 2 the animals did not settle well during the first period and, having trampled the sward rather more than they had grazed it, were moved onto the second, fresh area

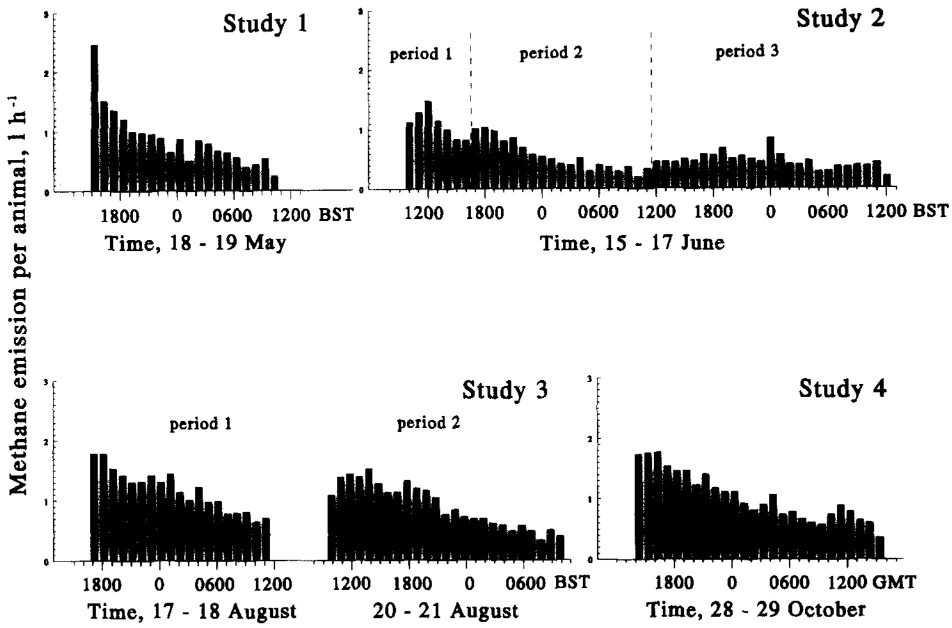

Fig. 3. Emission of methane by grazing sheep during four separate studies. Measurement started 1·5 – 2 h before sheep were introduced to the system.

of sward after 7 h. Here again, herbage was grazed very poorly. In the final period on the last third of the sward the herbage was grazed down to leave a uniform stubble. In Study 3 the sheep were hungry when moved into the polytunnel and grazed with enthusiasm. However, rising temperatures during the second day interrupted the study and the sheep were removed from the polytunnel. At the start of the second period the animals appeared to be grazing and ruminating normally but by the following day it was clear that only small patches of the sward had been eaten. The older sheep used in Study 4 took some time to settle but started to graze after about 3 h. By the following day some parts of the sward had been closely grazed but, as in most of the previous studies, grazing of the area was far from uniform.

Thus, in each of these studies there were periods when, from observation, the sheep behaved completely normally, grazing, resting and ruminating with no signs of stress. At other times the sheep were apparently restive and showed no eagerness to graze even when hungry, but such behaviour is also regarded as natural in sheep.

We were able to use these studies to make some initial assessment of the extent of CH_4 emission by grazing sheep. It should be noted that it is the net flux of CH_4 from the total grazed sward system that is calculated; the flux includes any emission or uptake of CH_4 by soil or plant and any influence that dung and urine might have had in this respect. However, relative to the amount of CH_4 released by the animals, these other processes would make a minimal contribution. Initial studies (Jarvis *et al.*, 1994) using an adjacent area of sward have shown daily fluxes ranging from an uptake of 1·35 g ha^{-1} CH_4–C to an emission of 2·93 g ha^{-1} CH_4–C. On a farm scale, Jarvis & Moss (1994) calculated that emission from dung in the field represented only about 0·2% of the total rumen emission of CH_4.

Apart from the initial high levels of release on introduction to the polytunnel, there were no other obvious diurnal or other patterns. It was possible to calculate the average daily amounts of CH_4 emitted per sheep, over similar periods in the four studies (Table 2). In Studies 1, 3 and 4 the daily rates of emission were broadly similar and in the range 14 – 19 g CH_4 day^{-1} per animal. The lower emission rates in Study 2 may have been associated with the generally poor grazing of

Table 2. Emissions of methane from grazing sheep

Study no.	Period no.	Period h	CH_4* emission per animal g day^{-1}	Maximum rate per animal g h^{-1}	Minimum rate per animal g h^{-1}
1	—	20	14·2	1·64	0·26
2	1+2	26	11·3	0·99	0·12
	3	25	7·7	0·56	0·19
3	1	19	18·7	1·12	0·43
	2	25	15·0	1·01	0·21
4	—	26	16·7	1·17	0·38

* 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 litre gas.

the herbage on offer in periods 1 and 2, which was reflected perhaps in a lower emission in period 3, even though grazing during this period was particularly effective. As already noted, maximum rates of emission were measured during the first few hours of each study when they generally exceeded 1·0 g h^{-1} per animal.

Interactions between herbage quality, consumption and the nutritional/physiological status of the animals may be very important. In contrast to a recent study with grazing cattle (Denmead, 1994), there was no obvious indication that the production of CH_4 from the sheep was periodic; as noted previously, more recent studies (Lockyer, 1994, unpublished data), extending over several days, have shown some periodicity in CH_4 production. In the case of the cattle study, peaks of emission occurred when animals were lying down and ruminating, with troughs during grazing periods and this cycle being repeated about every 3 h. Further studies will be required to establish whether animal species differ in this respect or whether husbandry influences patterns of emission.

The average rate of emission of CH_4 over our four studies was 14·0 g day^{-1} per animal, which is substantially lower than other estimates. Moss (1993) gives an estimate, based on losses of energy for this class of stock, of 10·5 kg $year^{-1}$ per animal, i.e. 28·8 g day^{-1} per animal. Other recent estimates range from 21·9 to 24·5 g day^{-1} per animal (Watt Committee on Energy, 1993). Using UK census data for June 1992 (MAFF, 1993), it can be estimated that the total flock of ewes and shearling sheep would emit 104 kt CH_4 into the atmosphere each year, with a further contribution from lambs and other sheep of 63 kt, assuming the same emission rate and that lambs, on average, will be present for only 6 months. A total emission of 167 kt $year^{-1}$ is approximately 11% of the total attributable to UK agriculture and 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.

Clearly, such overall figures should be treated with caution at this stage. However, the indications are that the system, as it has been developed, provides a sensitive and accurate method for measuring CH_4 emission from grazing animals and should provide improved estimates of this particular source and its contribution to CH_4 budgets and their environmental impact.

Compared with the method described by Denmead (1994), a variant of the mass balance approach, our system is portable and relatively inexpensive; CH_4 concentrations have only to be measured at the inlet and outlet of the polytunnel rather that at several heights on all sides of a paddock. Additional polytunnels with associated measurements could be incorporated easily into the present system, allowing suitable replication of treatments in formal experimentation. The intensity of CH_4 measurement allows fluctuations to be followed and makes fluxes simple to calculate and interpret. Any enclosure system, however, is a departure from truly natural conditions; temperature and humidity do depart quite markedly from concurrent ambient measurements, even if still within a realistic range, and exposure to wind is virtually eliminated.

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