Journal of Agricultural Science, Cambridge (1999), **133**, 439–444. *Printed in the United Kingdom*

A comparison of systems for measuring methane emissions from sheep

P. J. MURRAY[1]*, A. MOSS[2], D. R. LOCKYER[1] AND S. C. JARVIS[1]

[1] *Institute of Grassland and Environmental Research, North Wyke Research Station, Okehampton, Devon, EX20 2SB, UK*

[2] *ADAS Feed Evaluation and Nutritional Sciences, Drayton, Alcester Road, Stratford-on-Avon, Warwicks, CV37 9RQ, UK*

(*Revised MS received 26 May 1999*)

SUMMARY

Two experiments were conducted, at ADAS Drayton in the autumn and winter 1996/1997, to compare methane (CH_4) emissions from sheep housed either in a polytunnel system or in open-circuit respiration chambers. In each system, the sheep received maintenance levels of either cut grass or high temperature dried grass pellets (HTDG). All experiments in the tunnel were conducted on concrete to avoid any interactions of the CH_4 with the soil/plant environment. The results suggested that CH_4 production from the open-circuit chambers was greater than from the tunnel system ($26{\cdot}9 \pm 0{\cdot}46$ *v.* $31{\cdot}7 \pm 0{\cdot}35$ l/kg dry matter intake ($\pm$S.E.) for open circuit respiration chambers and tunnel, respectively). Recovery tests gave similar results for both systems (95·5–97·9% for tunnels and 89·2–96·7% for chambers), and confirmed that both methods give good quantitative recovery of added CH_4, and can therefore be assumed to provide reliable estimates of emissions from animals. There is no technical explanation, therefore, for the different estimates of emissions provided by the two systems. Further studies are required to understand the reasons for the differences and in particular, the possible links between animal behaviour induced by the two systems and CH_4 emission rates.

INTRODUCTION

Methane (CH_4) is one of the main greenhouse gases contributing to global warming. The most abundant of these gases is carbon dioxide (CO_2) which accounts for *c.* 60% of the greenhouse effect at present. However, CH_4 is 25 times more active in this respect per molecule than carbon dioxide (Rodhe 1990). The concentration of CH_4 in the atmosphere has been increasing over recent years at a rate of 0·5–1·1% per year (Bouwmann 1990; Steele *et al.* 1992) and it is estimated that CH_4 now contributes *c.* 18% of the global warming potential. Annually, *c.* 500 Tg/y of CH_4 are generated globally (Bandyopadhyay *et al.* 1996) and the main sources are from agriculture, with enteric generation by ruminants, rice paddies and biomass burning accounting for 65% of total emissions (Duxbury 1994). In the UK, it is estimated that 37% of CH_4 emissions can be almost entirely attributed to animal production systems (Watt Committee on Energy 1993). In order to make progress towards commitments to reduce emission of greenhouse gases, it is essential that the contributions of all sources and sinks should be accurately assessed.

Many current inventories for enteric CH_4 production are based on measurements of emission rates from animals in open circuit respirometers in strictly controlled environments, with specific diets linked to energy balances. Such studies give accurate results for emissions under such controlled conditions, but may not represent interactive effects under natural conditions. For example, many production systems are based on extended periods of grazing where the interactions between soil/plant/animal components of grazing systems may influence net emissions of CH_4 for a number of reasons. An alternative system, which involves housing animals in a polytunnel on grass swards, has been developed which enables the measurement of CH_4 fluxes under near-natural grazing conditions (Lockyer & Jarvis 1995). In previous studies with this system (Lockyer 1997), results indicated lower emission rates from sheep than those found using conventional respirometers. To provide reliable CH_4 budgets at a national level, it is necessary to confirm that these differences exist and, if so, to

* To whom all correspondence should be addressed. Email: phil.murray@bbsrc.ac.uk

provide some explanation for their causes. The present study therefore sought to determine CH_4 emissions from sheep, measured in parallel experiments in respirometers and in the polytunnel system. This was done in order to establish whether the differences previously found were real and, if so, to develop some understanding of their causes.

MATERIALS AND METHODS

The two systems for measuring CH_4 emissions from sheep, which were compared in a series of studies, were as follows.

Tunnel system

The system used to assess CH_4 emissions from grazing animals has been described in full by Lockyer & Jarvis (1995) and has been used in a number of studies with sheep (Lockyer 1997). Briefly, it consists 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 concentrations of CH_4 in the air entering and leaving the tunnel and (iv) apparatus to monitor and record airspeeds and temperatures. The large tunnel (polytunnel) is a commercial, polythene-clad greenhouse modified to make it portable; it is 4·3 m wide, 9·9 m long with a height of 2·1 m at the ridge, giving an approximate volume of 66 m^3. The framework of the tunnel is covered with white polythene sheeting which is drawn down at each end to connect to each of the small wind-tunnels (described by Lockyer 1984). Each wind-tunnel consists of a steel duct, 1·5 m long and 0·4 m internal diameter, housing a co-axial fan and a vane anemometer. Airflow through each tunnel can be controlled at rates of up to 1·0 m^3/s. The output of each anemometer is recorded by a data logger (Delta-T Devices Ltd. Cambridge, UK) to provide an integrated measurement of airspeed from which the volume flow of air through the tunnel can be calculated.

Methane concentrations in air entering and leaving the polytunnel are measured using an automatic sampling system connected to a gas chromatograph (GC) fitted with a flame ionization detector (FID). Air is drawn continuously from two sampling points, one near the inlet to the polytunnel and one within the small wind-tunnel that forms the outlet. A sampling unit, under the control of a data logger (Campbell Scientific Ltd, Shepshed, UK), allows samples (2·0 ml) to be taken in turn from the inlet and outlet air and injected automatically onto the GC column; the output from the FID is scanned continuously by the data logger which is also programmed to detect, integrate and record each CH_4 peak. Concentrations are then calculated from a standard curve prepared after measuring the response of the FID to known concentrations of CH_4 in helium. Typically, peak concentrations rise to *c.* 10 ml/l which can be detected with an accuracy of *c.* 0·4% over the measurement range.

Open-circuit respiration chambers

The four open-circuit respiration chambers used were of stainless steel and Perspex construction (*c.* 2·4 m^3 volume) and similar in operation to that described by McClean & Tobin (1987). Dry gas meters were fitted in the pipework between the chambers and the air suction pumps (60 l/min) to measure the total volume of gas passing through each chamber. Continuous subsampling of the outflow gas from each chamber at 3 minute intervals for each were analysed, with the incoming air, for CH_4 by passing it through an infrared CH_4 analyser (Analytical Development Company Ltd, Hoddesdon, UK) and the absorption determined at wavelength 3·29 μm. Methane volume was adjusted to standard temperature and pressure and the infrared analyser was calibrated daily.

Experimental procedures

In all experiments, measurements were made with Clun wether sheep (approx. 60–70 kg liveweight). Two groups of four sheep were maintained as the experimental animals. These animals were kept in the same groups throughout the studies. A further two sheep were maintained over the entire study period on the appropriate diet so that they could be used as replacement animals if needed, however, this was not necessary. In addition to receiving the relevant diet, each sheep received 7·0 g/day of a sheep mineral/vitamin supplement. The animals were allowed to acclimate to the appropriate diet for a period of 14 d before each study. The sheep were weighed at the start of each acclimatization period and at the start and end of each measurement period.

The comparison between systems was carried out using two feed types. One was grass that was harvested (direct cut forage harvester) from a sward at ADAS Drayton on 12 September 1996. The sward consisted predominantly of perennial ryegrass and had received fertilizer to supply 50 kg/ha of N on 18 May 1996. The grass was thoroughly mixed, bagged and stored frozen at −18 °C with sufficient material to provide daily rations for an approximate maintenance allowance for the experimental animals. The ration was thawed prior to feeding to the animals. The second feed that was offered was a ration of High Temperature Dried Grass (HTDG) pellets. Feeding allocations were provided which again met maintenance requirements.

For these studies the polytunnel was positioned over a concrete base. Tests showed that more air was able to leak into the tunnel in this situation than when it has been used previously on grass swards (Lockyer & Jarvis 1995). The wind tunnel used at the inlet was

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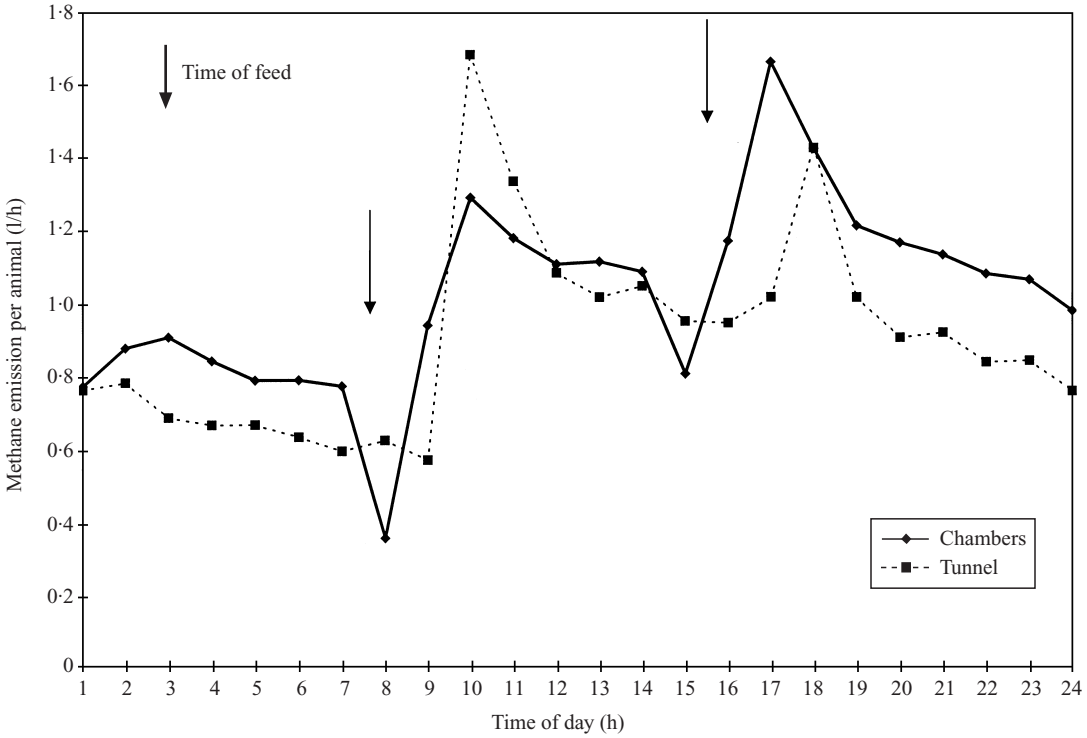

Fig. 1. Mean hourly methane emission (l/animal/h) from sheep fed a maintenance diet of HTDG pellets, either in chambers (unbroken line) or in the polytunnel (dashed line), showing time of feeding (↓).

therefore not required and the inlet was closed, sufficient air being able to enter the polytunnel from under the perimeter to meet the required airflow of 0·25 m^3/s. The sampling point for measuring background CH_4 concentration was positioned *c.* 2 m upwind of the tunnel. Metal hurdles were used to form four pens within the polytunnel, each provided with a water container and feeding bin. One animal was allocated to each pen, where it was able to maintain visual contact with its fellows. Measurement of CH_4 concentration began about 15 min before animals were moved into the tunnel.

Each animal was offered its daily ration of feed in two equal portions given at about 09.00 h and 17.00 h. Any food not eaten by the time of the next feed was removed and weighed to allow an estimate to be made of the DM intake of each animal. The animals were removed from the tunnel at the end of each run and transferred to the open-circuit respiration chambers, where the measurements followed the same procedures as those described above. The animals removed from the tunnels were replaced with the second group of four, and again the measurements followed the procedures described previously.

Emissions of CH_4 in the chambers and the tunnel were compared using the mean-square prediction error (GENSAT procedure MSPE) (Rook *et al.* 1990). In the present study, the values from the chambers, being the established technique, are regarded as the 'actual' values, and those from the tunnels, being the system under test, as the 'predicted' values.

Recovery tests of CH_4

In the polytunnel system, with an air flow at the outlet set at 0·25 m^3/s, pure CH_4 was released from a gas cylinder at 200 ml/min into the polytunnel through a precision flowmeter and needle valve. The increase in CH_4 concentration above background concentration, measured at the outlet, reached 95·6% of the theoretical value within 15 min. In terms of quantitative recovery, 6·85 l of CH_4 was measured leaving the polytunnel, i.e. 97·9% of the 7·0 l added in 35 min.

To test the recovery of CH_4 from the chambers a gravimetric method was used. Pure CH_4 was released at 30 ml/min into each chamber from a small gas cylinder for 3 h followed by 60 ml/min for 2 h with an air flow at the outlet set at 60 l/min. The cylinder was weighed at the start and finish of the release periods to determine the weight of CH_4 released. Temperature, relative humidity, barometric pressure and CH_4 concentration were measured at 15 min intervals for 23·5 h. The mean overall quantitative CH_4 recovery was 92·6% (S.E. = 1·55), mean recoveries for

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individual chambers were 89·2, 92·7, 96·7 and 91·9 for chambers 1–4, respectively. A similar gravimetric test was also done in the polytunnel at the end of the experiments and gave a mean recovery of 95·5% of the CH_4 added.

RESULTS

Throughout all the studies where the animals were fed to a strict regime, both in the chambers and in the tunnels, there were marked trends in CH_4 emission, with a rapid rise directly after feeding. The impact of the first feed was greater than the second (Figs 1 and 2). This was especially marked with the HTDG diet and was repeated over several days (Fig. 3). This contrasts markedly with the pattern of emission seen in previous studies of animals grazing in the polytunnels (Lockyer & Jarvis 1995) where there was a diurnal trend with a peak in emission between 15.00 h and 16.00 h and the minimum at around 09.00 h. Daily emission rates, however expressed, were similar within systems and within feed types for zero-grazing and HTDG. CH_4 production (l/kg dry matter intake) regardless of system of measurement, was higher for the frozen and thawed herbage than for the HTDG pellets (32·6 *v.* 31·0 l/kg dry matter intake, respectively, for chambers).

The mean CH_4 emissions and their standard errors from the two systems are shown in Table 1, together with the MSPE, the proportion of MSPE attributable to mean bias, line bias and random error, the mean bias, and the line mean prediction error (MPE) expressed as a proportion of the observed CH_4 release. The high bias in the predicted error indicates that the systems were performing in the same manner but the tunnel system gave consistently lower results.

DISCUSSION

Total CH_4 losses from sheep in the UK are estimated to be *c.* 130 kt (Sneath *et al.* 1997). This estimate was based on measurements from individual animals which ranged from 29 g/d (Moss 1993) and 22 g/d (Crutzen *et al.* 1986) to 14 g/d (Lockyer & Jarvis 1995). The first two figures have been derived from animals in respiration chambers, the latter from a limited number of measurements from animals held in a polytunnel system. The present study confirms the previous indications that animals in the tunnel system produce consistently lower CH_4 emission values than when in the open-circuit respiration chambers. Within both systems there was a constancy of emission per animal over each 24 h period; given the similarities of

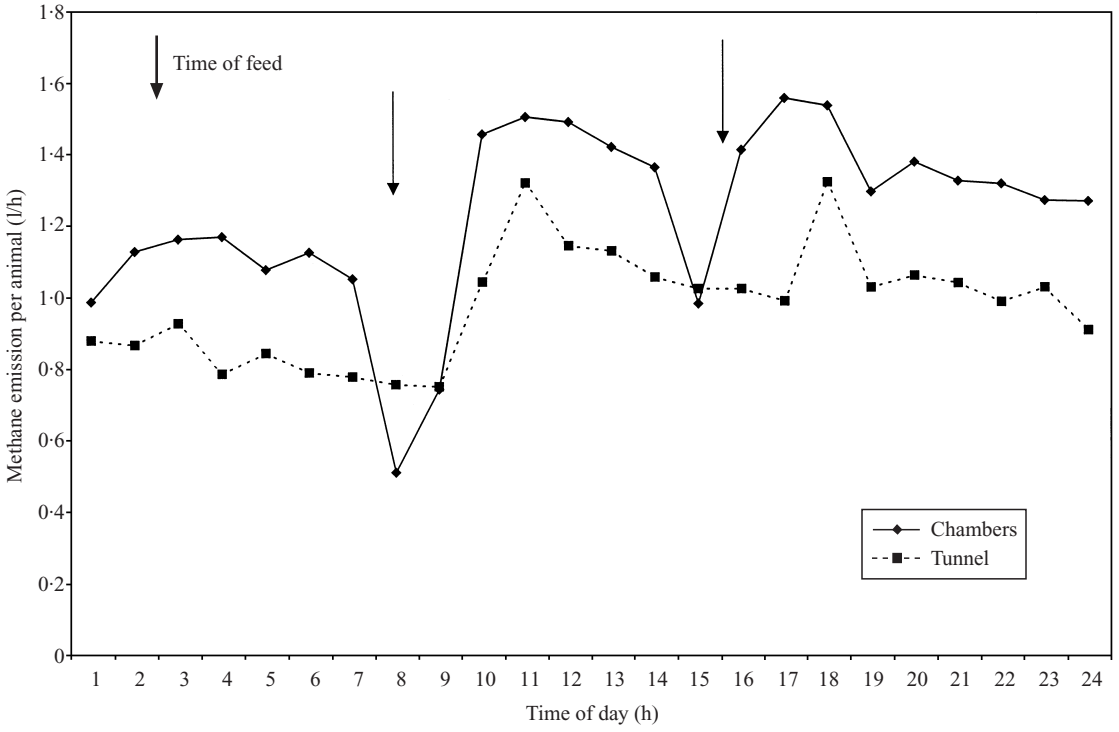

Fig. 2. Mean hourly methane emission (l/animal/h) from sheep fed a maintenance diet of previously frozen grass, which was allowed to thaw prior to feeding, either in chambers (unbroken line) or in the polytunnel (dashed line), showing time of feeding (↓).

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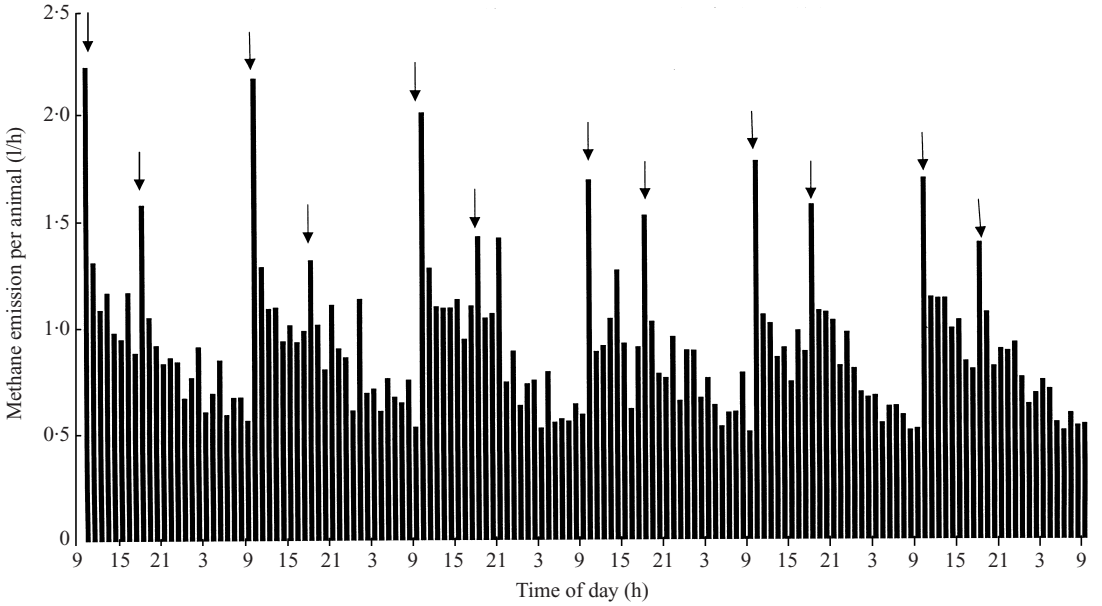

Fig. 3. Mean hourly methane emission (l/animal/h), over 6 days, from sheep fed a maintenance diet of HTDG pellets in the polytunnel, showing impact of feeding time (↓).

Table 1. *Prediction precision of CH_4 emissions as measured in respiration chambers and in a tunnel (polytunnel) system*

	Chamber		Tunnel		Proportion of MSPE					
	Mean	S.E.	Mean	S.E.	MSPE	Bias	Line	Random	Bias	MPE
l/kg DMI	25·80	0·587	22·47	0·317	15·32	0·725	0·001	0·273	−3·33	15·17
l per animal/d	31·73	0·354	26·93	0·459	26·27	0·879	0·057	0·064	−4·81	16·15

the diets in the two studies, and the differences found between the two systems it is apparent that something other than chemical composition of the diet influenced emissions. The reasons for the differences are not clear. Recoveries of added CH_4 from both systems were similar and very good and there were apparently no systematic differences in errors in measurement related to the two sampling systems. It can only be that the food processing and utilization in the rumen was affected by the conditions imposed by housing of the animals.

Possibilities that should be considered are the effect of ambient temperature and/or animal behaviour on the metabolism of the animal or on ruminal fermentation. The two measurement systems differ in environmental control; the respiration chambers are controlled to maintain a temperature of 16 °C and relative humidity of 60 %, whereas the tunnel has no control mechanism, so temperature and humidity will be directly determined by the ambient conditions. The zero-grazing and HTDG studies were not run concurrently for the two systems and the studies in the tunnel commenced in December and were completed in early February. Mean ambient temperatures were significantly below the 16 °C maintained in the chambers. For unshorn sheep with a fleece length of approximately 100 mm there would be no energy expenditure to maintain body heat above normal heat production unless the ambient temperature fell below −3 °C (Blaxter 1962). Whilst these lower temperatures were unlikely to have caused cold stress for the sheep, the water on offer would have been at the same low ambient temperature and the ingestion of cold water will lower the rumen temperature. It has previously been observed (Church 1973) that ingestion of water, even at a moderate temperature (25 °C) will result in a drop in rumen temperature of 5–10 °C and that as much as 2 h may be required for this to become stable after drinking. The drop in rumen temperature, which is likely to be greater for the animals in the tunnel, would limit microbial activity and in turn reduce feed fermentation and hence CH_4

production. Feed digestibility and utilization were not determined for the animals during the time in the tunnel.

Methane production has been shown to be inversely related to rumen passage rate and increased ruminal passage rate is associated with cold adaptation. Kennedy & Milligan (1978) reported increased ruminal passage rate constants of fluid and particulate matter of 54 and 68 %, respectively, with cold adapted sheep and a subsequent 30 % decrease in CH_4 production. In addition, Kennedy & Milligan (1978) found a decrease in the acetate:propionate ratio in cold-acclimatized sheep, which suggests a shift from CH_4 to propionate production (Fahey & Berger 1988). The above observations were made with sheep fed at maintenance. Other workers have observed the opposite effect when the cold acclimatized animals were allowed to increase their dry matter intake to compensate for the cold conditions (von Keyserlingk & Mathison 1993). Rogerson (1960) found that the effects of temperatures between 20 and 40 °C on CH_4 production were variable. The evidence to date on the effect of environmental temperature on CH_4 production is, however, limited and requires further research. The daily patterns displayed under different feeding regimes are also of some interest and consequence. The large flux when animals were fed at set times is perhaps indicative of a physical displacement of CH_4 already generated. The consequences of this for overall emissions are not known.

The differences in CH_4 production from the two systems have implications for estimates of global CH_4 emissions, in that, if the tunnels more accurately reflect field conditions than do chambers, measurements from the latter are likely to result in an overestimate of global methanogenesis from ruminants most of which spend only small periods of their time indoors. Chamber-based estimates may be more appropriate for animals which are housed for significant periods.

This work was funded by the Ministry of Agriculture, Fisheries and Food, London. The Institute of Grassland and Environmental Research is supported by the Biotechnology and Biological Sciences Research Council. We are grateful to Dr A. J. Rook for statistical advice.

REFERENCES

Bandyopadhyay, T. K., Goyal, P. & Singh, M. P. (1996). Generation of methane from paddy fields and cattle in India, and its reduction at source. *Atmospheric Environment* **30**, 2569–2574.

Blaxter, K. L. (1962). *The Energy Metabolism of Ruminants*. London: Hutchinson.

Bouwmann, A. F. (1990). Land use and related sources of greenhouse gases. *Land Use Policy* **7**, 154–164.

Church, D. C. (1973). *Digestive Physiology and Nutrition of Ruminants. Vol. 1 – Digestive Physiology*. Corvallis OR: O & B Books.

Crutzen, P. J., Aselman, I. & Seiler, W. (1986). Methane production by domestic animals, wild ruminants, other herbivorous fauna and humans. *Tellus* **38B**, 271–284.

Duxbury, J. M. (1994). The significance of agricultural sources of greenhouse gases. *Fertilizer Research* **38**, 151–163.

Fahey, G. C. & Berger, L. L. (1988). Carbohydrate nutrition of ruminants. In: *The Ruminant Animal: Digestive Physiology and Nutrition* (Ed. D. C. Church), pp. 269–297. Englewood Cliffs, NJ: Prentice-Hall.

Kennedy, P. M. & Milligan, L. P. (1978). Effects of cold exposure on digestion, microbial synthesis and nitrogen transformations in sheep. *British Journal of Nutrition* **39**, 105–117.

Lockyer, D. R. (1984). A system for the measurement in the field of losses of ammonia through volatilisation. *Journal of the Science of Food and Agriculture* **35**, 837–848.

Lockyer, D. R. (1997). Methane emissions from grazing sheep and calves. *Agriculture, Ecosystems and Environment* **66**, 11–18.

Lockyer, D. R. & Jarvis, S. C. (1995). The measurement of methane losses from grazing animals. *Environmental Pollution* **90**, 383–390.

McClean, J. A. & Tobin, G. (1987). *Animal and Human Calorimetry*. Cambridge: Cambridge University Press.

Moss, A. R. (1993). *Methane: Global Warming and Production by Animals*. Canterbury: Chalcombe Publications.

Rodhe, H. (1990). A comparison of the contributions of various gases to the greenhouse effect. *Science* **248**, 1217–1219.

Rogerson, A. (1960). The effect of environmental temperature on the energy metabolism of cattle. *Journal of Agricultural Science, Cambridge* **55**, 359–366.

Rook, A. J., Dhanoa, M. S. & Gill, M. (1990). Prediction of the voluntary intake of grass silages by beef cattle. 3. Precision of alternative prediction models. *Animal Production* **50**, 455–466.

Sneath, R. W., Phillips, V. R., Demmers, T. G. M., Burgess, L. R., Short, J. L. & Welch, S. K. (1997). Long-term measurements of greenhouse gas emissions from U. K. livestock buildings. In *Proceedings of the Fifth International Livestock Environment Symposium, Vol. I* (Eds R. W. Bottcher & S. J. Hoff), pp. 146–153. Minneapolis-St Paul: A.S.A.E.

Steele, P., Dlugokencky, E. J., Lang, P. M., Tans, P. P., Martin, R. C. & Masane, K. A. (1992). Slowing down of the global accumulation of atmospheric methane during the 1980's. *Nature* **358**, 313–316.

von Keyserlingk, G. E. M. & Mathison, G. W. (1993). The effect of ruminal escape protein and ambient temperature on the efficiency of utilization of metabolisable energy by lambs. *Journal of Animal Science* **71**, 2206–2217.

Watt Committee on Energy (1993). *Methane Emissions*. London: The Watt Committee on Energy.