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Methane emission from dairy cows and wether sheep fed subtropical grass-dominant pastures in midsummer in New Zealand

M. J. ULYATT[1]*
K. R. LASSEY[2]
I. D. SHELTON[1]
C. F. WALKER[2]
[1]AgResearch Limited
Private Bag 11 008
Palmerston North, New Zealand

[2]National Institute of Water and Atmospheric Research Limited
P.O. Box 14 901
Wellington, New Zealand

*Present address: 181 Omokoroa Road, RD2, Tauranga.

Abstract Methane emission was measured from 10 dairy cows and 12 wether sheep grazing kikuyu grass- (*Pennisetum clandestinum*) dominant pastures at Waimate North, Northland, in February 1997 and March 1999, and from 10 dairy cows grazing summer grass- (*Digitaria sanguinalis*) dominant pasture at Edgecumbe, Bay of Plenty, in March 2000. Methane emission was measured from each animal for 5 consecutive days in each measurement period using the sulphur hexafluoride (SF_6) tracer gas technique. Analysis of variance of the kikuyu grass chemical composition with sheep and cow data combined showed that the 1999 pastures were significantly higher in protein ($P < 0.01$), soluble sugars ($P < 0.001$), lipid ($P < 0.01$), and dry matter (DM) digestibility ($P < 0.001$) and lower in ash ($P = 0.023$), acid detergent fibre (ADF) ($P < 0.001$), and neutral detergent fibre (NDF) ($P < 0.001$) than the 1997 pastures, presumably as a consequence of urea topdressing in 1999. The chemical composition of the summer grass-dominant pasture grazed by cows in 2000 was similar to the kikuyu grass, except that DM digestibility was higher. Daily methane emissions from kikuyu grass were 363 and 167 g/day for the cows and 15.6 and 4.4 g/day for the sheep in 1997 and 1999, respectively. These corresponded to methane yields (MYs, methane energy as a percentage of gross energy) of 7.1 and 3.8% for the cows and 6.3 and 1.9% for the sheep in 1997 and 1999, respectively. There was clearly a significant inhibition ($P < 0.001$) of methane production in 1999 in both species fed kikuyu grass. Methane emission was 422 g/day and MY 6.7% in the cows fed summer grass, values that were similar to the kikuyu-fed cows in 1997. Methane emitted in g/kg digestible DM intake was 33.8 and 38.2 for the 1997 kikuyu grass-fed cows and sheep and 33.3 for the summer grass-fed cows. This suggests that methane emitted per unit of digested DM is higher for ruminants fed subtropical (C4) grasses than those fed temperate (C3) grasses and we believe it to be related to the higher cell wall content of C4 grasses.

Keywords methane emission; subtropical pastures; grazing; dairy cows; sheep

INTRODUCTION

In a survey of New Zealand pasture species abundance conducted over the 1987–89 period, Field & Forde (1990) made comparisons with previous surveys and noted an increased spread southwards of subtropical C4 grasses, which they associated with climate warming. This trend has probably continued in the subsequent decade because in 1998 and 1999 environmental temperatures in New Zealand were the highest since records began in 1855 (M. J. Salinger pers. comm.).

The C4 grasses generally have a higher cell wall carbohydrate content and a lower dry matter (DM)

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digestibility than temperate grasses at the same stage of growth (Minson 1981). Blaxter & Wainman (1964) and Moe & Tyrell (1979) showed that as the proportion of cell wall carbohydrate increases in the diet of cattle and sheep at high feed intake levels, their methane emissions also increase. Therefore, it would be expected that methane emission from C4 grasses would be higher than from C3 plants at the same level of intake. This appears to be the case, as Margan et al. (1988) found that sheep fed tropical grasses had a higher methane yield (MY, methane energy as a percentage of gross energy intake) of 7.4% compared with sheep fed temperate forages (6.0%), whereas McCrabb & Hunter (1999) found higher values of 10.4 and 11.4% for the same parameter from cattle fed two tropical grasses. From this type of data it can be argued that as environmental temperatures increase, C4 grasses will spread southwards and as a result animal productivity will decline and methane emission per unit of product will increase.

Two C4 grasses have been chosen as examples to study methane emission in the present work. The perennial grass, kikuyu grass (*Pennisetum clandestinum*), was introduced into Northland in 1920 (Elliot 1925) and has spread, through both deliberate planting and by natural means, to most of the North Island since then (Field & Forde 1990). It achieves dominance mainly in Northland and the Bay of Plenty. The annual summer grass (syn. crabgrass) (*Digitaria sanguinalis*), was first recorded in New Zealand in 1855 and is now an abundant weed in waste areas and cultivated land throughout the country (Field & Forde 1990). Summer grass has recently become a problem in dairy pastures in the Waikato and Bay of Plenty districts, constituting in some locations over 50% of the pasture (Field & Forde 1990; Wardle et al. 1994).

MATERIALS AND METHODS

Measurements of methane emission were made from dairy cows and wether sheep grazing C4 grass-dominant pastures at two locations in the North Island of New Zealand. Pastures containing the perennial kikuyu grass were grazed in February 1997 and March 1999 at a commercial farm at Waimate North, Northland (35.3°S, 173.9°E). A further set of measurements was made with dairy cows grazing a pasture containing the annual summer grass on a commercial farm near Edgecumbe in the Bay of Plenty (38°S, 176.7°E) in March 2000. The dates were chosen to try to ensure that the C4 grasses were at maximum growth rate.

Animals

The cows in all the experiments were predominantly Friesians. In the kikuyu 1997 experiment they were on average 6.3 ± 3.1 (SD) years old, weighed 440 ± 46 kg, were 207 ± 25 days into their lactations and were 108 ± 40 days in calf (1 non-pregnant). In the kikuyu 1999 experiment these values were 5.5 ± 2.1, 493 ± 42, 184 ± 12, and 121 ± 5 (5 non-pregnant) and for the summer grass experiment 7.2 ± 2.8, 585 ± 59, 220 ± 23, and 130 ± 19 (1 non-pregnant), respectively. Ten cows were used in each experiment and there were no cows common between any experiments. The cows were accustomed to wearing a leather halter to facilitate exhaled gas collection.

The 12 sheep used in each kikuyu experiment were Romney cross wether lambs c. 6 months of age and weighing 34.5 ± 2.5 (SD) kg in 1997 and 36.8 ± 2.2 kg in 1999. The wethers were trained to wear a halter and PVC yoke as well as a faeces collection harness and bag for 7 days before any measurement.

Pasture management

The sheep and cattle were grazed on separate paddocks in the kikuyu grass experiments, with the same paddock assigned to each livestock class in both 1997 and 1999. The amount of herbage on offer was assessed to be well in excess of 5000 kg/ha in all experiments. Herbage on offer was not measured because the dense mat of rhizome would have made cutting to ground level meaningless. Pastures were managed by rotational grazing using electric fences to ensure that each day the animals were given an allocation well in excess of 2.5 times their estimated daily requirements. The sheep were introduced to their paddock 10 days before the measurement period and remained there for the entire experiment. The dairy cows were introduced to their paddock 3 days before the measurement period, but they had been grazing similar pasture in the course of their normal pasture rotation. In 1999, to reduce the presence of white clover, both the sheep and the cow pastures were topdressed at the beginning of December, January, February, and March with urea at 120 kg/ha (56 kg N/ha) on each occasion.

A similar pasture management system was used for the cows grazing the summer grass-dominant pasture. The cows were introduced to the pasture 10 days before the 5-day measurement period. The amount of herbage on offer during the measurement period, measured from 0.1 m^2 quadrates cut to ground level, was 4017 kg/ha. The cows were allocated a daily allowance well in excess of their requirements.

Methane emission measurement

Methane emission was measured on grazing animals using the sulphur hexafluoride (SF_6) tracer technique of Johnson et al. (1994) as described by Ulyatt et al. (2002). Permeation tubes containing SF_6 were dosed *per os* into the reticulo-rumen at least 10 days before the start of any measurement period. Continuous samples of exhaled gases containing both SF_6 and methane were collected into evacuated PVC yokes placed on the animals' necks. Following gas analysis for both methane and SF_6 by gas chromatography, methane emission rates were calculated from the gas concentration ratios and the calibrated SF_6 permeation rates (Lassey et al. 1997; Ulyatt et al. 1999).

Feed intake estimation

The feed intake of the dairy cows was estimated using the requirements model detailed by Ulyatt et al. (2002).

The feed intake of the wether sheep was calculated from the feed DM digestibility (determined by near infra-red reflectance (NIR) technology calibrated against *in vivo* digestibility data) and total collection of faeces over the methane measurement period using a harness and faeces collection bag (Lassey et al. 1997).

Sampling and analysis

Pasture samples were taken daily by hand cutting (sheep) or plucking (cows) 15 transects of c. 2 m from each pasture immediately before giving the animals access to their daily allocation. The sample height was judged from the residual left by the animals on the previous day. Each day's total sample from each pasture was mixed and then a subsample taken and dried overnight at 60°C before chemical and digestibility analysis by NIR (NIRSystems 6500). Subsamples for botanical analysis were taken on the third day of the measurement period.

Total faeces were collected from the sheep twice a day, at c. 0830 and 1600 h on Days 2–6 of the measurement period. These were weighed daily, an aliquot taken for dry matter determination (80°C for 24 h) and an aliquot for chemical analysis frozen, bulked for the collection period and dried at 60°C.

The experimental paddocks were dominantly kikuyu grass and for this reason in 1997 no pasture sample was taken for botanical analysis during the experimental period. In retrospect, there was a concern that the sheep might have preferentially grazed the small amount of white clover that was present in their paddock, so a sample of the sheep pasture was taken at the end of the experiment, separated manually into kikuyu grass and white clover and these fractions oven dried overnight at 60°C. These fractions, together with plant and faeces samples that had been collected for chemical analysis from the 1997 sheep experiment, were analysed for their *n*-alkane content by gas chromatography (Hewlett Packard, Series II) using the method of Mayes et al. (1986).

Milk yield was determined by twice-daily measurements. Samples were taken at each milking for fat and protein analysis using an infra-red milk analyser (Milkoscan 133B, Foss).

Data are presented as the means for each livestock class/pasture type. Differences between years for the kikuyu grass comparisons were analysed by analysis of variance using the Genstat 5 (release 4.2) program. Individual animals were omitted from the statistical analysis if insufficient methane collections were completed or the results were judged to be outliers.

RESULTS

The botanical composition of the pastures used in 1999 and 2000 are presented in Table 1. The 1999 sheep kikuyu pasture contained small amounts of perennial ryegrass and white clover, while the 1999 kikuyu cow pasture was close to 100% pure. In the summer grass pasture the dominant species was *Digitaria sanguinalis* with a strong presence of perennial ryegrass and c. 10% weeds.

Samples for botanical analysis were not taken at the time of the 1997 kikuyu grass experiment because the pastures were observed to be predominantly kikuyu grass with only a trace of white clover. To examine the possibility that the sheep in the 1997 experiment might have selectively grazed the small amount of white clover present in the kikuyu grass-dominant pasture, samples of white clover and kikuyu grass collected at the end of the measurement period, along with bulked faeces

Table 1 Botanical composition of the pastures used in the experiments. (–, not included in analysis; 0, included in analysis but none was present.)

	Perennial ryegrass	Summer grass	Kikuyu grass	Other grasses	White clover	Weeds	Dead matter
Kikuyu grass pasture							
Sheep 1999	3.7	–	94.9	0	1.4	0	0
Cows 1999	0.2	–	99.6	0	0	0.2	0
Summer grass pasture							
Cows 2000	32.7	48.6	–	1.1	1.6	10.3[1]	5.7

[1]5.3% dandelion (*Taraxacum officinale*), 1.6% yarrow (*Achillea millefolium*), 1.3% creeping mallow (*Modiola caroliniana*), 2.1% *Ranunculus* spp.

samples from the animals, were analysed for their *n*-alkane composition. Results of this analysis are presented in Table 2. The ratios of C33/C35 *n*-alkanes in white clover and kikuyu grass were very different, while the faeces ratio was essentially identical to kikuyu grass, suggesting that little white clover was consumed by the animals (Dove & Mayes 1996).

The chemical composition of all the pastures is presented in Table 3. For sheep grazing kikuyu grass the concentrations of ash, acid detergent fibre (ADF), and neutral detergent fibre (NDF) were significantly higher in 1997, whereas soluble carbohydrate and DM digestibility were lower in 1999. The only change between the cow kikuyu pastures was that protein concentration was significantly higher in 1999 than 1997. Analysis of variance with sheep and cow data combined showed that the 1999 pastures were significantly higher in protein ($P < 0.01$), soluble sugars ($P < 0.001$), lipid ($P < 0.01$), and DM digestibility ($P < 0.001$) and lower in ash ($P = 0.023$), ADF ($P < 0.001$), and NDF ($P < 0.001$) than the 1997 pastures.

The chemical composition of the summer grass-dominant pasture was similar to the kikuyu grass, the major difference being its higher DM digestibility, possibly as a result of a comparatively high perennial ryegrass content (Table 1).

Table 2 Concentrations of C_{33} and C_{35} alkanes and their ratios in kikuyu grass and white clover and the faeces of sheep grazing pasture containing these two pasture plants in 1997.

	Alkane concentration (mg/100 mg DM)		Ratio
	C_{33}	C_{35}	C_{33}/C_{35}
Kikuyu grass	19.9	13.9	1.43
White clover	1.3	0.4	3.14
Faeces	53.1	37.4	1.42

The methane emission and production data of dairy cows grazing kikuyu and summer grass pastures is given in Table 4. The cows fed on kikuyu grass were significantly heavier in 1999 than 1997, however their DM intakes were higher in 1997. Milk yield followed DM intake, being higher in 1997. A statistical comparison between the cows grazing summer grass-dominant pasture and those fed kikuyu was not appropriate, however the cows fed on summer grass were clearly heavier, ate more, and had a higher milk yield. All measures of methane emission in the cows fed kikuyu grass were very significantly lower in 1999 than in 1997. The cows fed summer grass-dominant pasture had a high methane emission, in line with their feed intakes, while methane emissions per unit of feed intake (g/kg DM intake, g/kg digestible DM intake and MY) were lower than, but close to, the 1997 values for kikuyu grass.

Table 5 presents methane emission data for the sheep fed kikuyu grass. There was a small, but significant, difference in bodyweight in favour of the 1999 sheep. There was, however, no significant difference in DM intake between the two years. As with the dairy cows, all measures of methane emission showed a significantly lower value in 1999 than in 1997. This reduction was relatively more marked in the sheep than in the dairy cows. Methane emissions per unit of feed intake (g/kg DM intake, g/kg digestible DM intake, and MY) in 1997 were similar to the 1997 values for the dairy cows and the cows fed summer grass.

DISCUSSION

This study was planned to measure the level of methane emission from ruminants fed subtropical C4 grasses to make comparisons with the emissions from the perennial ryegrass/white clover pastures

Table 3 Chemical composition and DM digestibility of kikuyu and summer grass-dominant pastures grazed by dairy cows and sheep. (ADF, acid detergent fibre; NDF, neutral detergent fibre; DM, dry matter.) For kikuyu grass, within animal species, means with different superscripts within a column are significantly different between years ($LSD_{0.05}$).

	Crude protein	Soluble carbo-hydrate	Lipid	ADF	NDF	Ash	DM digestibility (%)
Kikuyu grass							
Sheep 1997	21.9[a]	6.2[a]	4.3[a]	27.5[a]	48.1[a]	10.0[a]	61.2[a]
Sheep 1999	23.4[a]	8.2[b]	4.7[a]	24.2[b]	43.1[b]	9.7[b]	64.1[b]
Cows 1997	22.6[a]	5.3[a]	4.4[a]	27.6[a]	48.8[a]	10.3[a]	61.4[a]
Cows 1999	25.6[b]	7.0[b]	4.7[a]	23.6[b]	41.5[b]	9.8[a]	63.9[b]
Summer grass							
Cows 2000	24.5	7.4	4.5	26.3	45.7	9.9	67.0

Table 4 Production characteristics and methane emission (g/day; g/kg DM intake (DMI); g/kg digestible DM intake (DDMI); MY, methane yield: methane energy as a percentage of dietary energy) from dairy cows grazed on pastures dominant in kikuyu grass or summer grass. (SED, standard error of the difference between means.)

	Kikuyu grass				Summer grass
	1997	1999	SED	*P*	2000
n	9	8			8
Bodyweight (kg)	438	487	22.1	0.044	585
DM intake (kg/day)	15.6	13.3	0.7	0.005	18.9
Milk yield (kg/day)	11.15	7.70	0.90	<0.001	14.50
Methane emission					
g/day	363	167	26.1	<0.001	422
g/kg DMI	23.4	12.6	1.82	<0.001	22.3
g/kg DDMI	38.2	19.7	2.92	<0.001	33.3
MY	7.1	3.8	0.56	<0.001	6.7

Table 5 Production characteristics and emission (g/day; g/kg DM intake (DMI); g/kg digestible DM intake (DDMI); MY, methane yield: methane energy as a percentage of dietary energy) from sheep grazing kikuyu grass at two different seasons. (SED, standard error of the difference between means.)

	1997	1999	SED	*P*
n	10	12		
Bodyweight (kg)	34.5	36.8	1.01	0.031
DM intake (g/day)	758	697	43.2	0.178
Methane emission				
g/day	15.6	4.4	0.92	<0.001
g/kg DMI	20.7	6.4	1.20	<0.001
g/kg DDMI	33.8	10.0	1.94	<0.001
MY	6.3	1.9	0.36	<0.001

more prevalent in New Zealand. Such C4 grasses, because of their relatively high cell wall content, have been reported to produce a higher methane emission from ruminants per unit of feed intake than temperate grasses (Margan et al. 1988; Kurihara et al. 1999). This could have an impact on New Zealand's methane inventory if C4 plants continue to replace C3 plants in their southwards migration as a consequence of environmental warming (Field & Forde 1990).

The NDF contents of the kikuyu grass pastures (Table 3) were within the range found in previous studies in New Zealand (Bailey & Hunt 1973; Joyce 1974; Betteridge 1979). The DM digestibilities given in Table 3 were also similar to the value of

61.4% for the *in vivo* determination of Joyce (1974). Bailey & Hunt (1973) and Betteridge (1979) also showed that kikuyu grass pastures had a higher content of NDF than contemporary perennial ryegrass pastures. The NDF contents of the kikuyu pastures in the present study, which averaged 48.5% for 1997 and 42.3% for 1999, were also higher than the mean value of 40.8% for the perennial ryegrass-dominant pastures used in March 1998 for methane emission measurements by Ulyatt et al. (2002). It would therefore be reasonable to expect kikuyu grass pastures to have a higher NDF content than perennial ryegrass-dominant pastures when compared at the same time of the year.

The composition of the summer grass-dominant pasture was similar to the kikuyu grass pastures (Table 3) with the exception that DM digestibility was higher. Samples of pure summer grass were not analysed for chemical composition in the present work. However, pure summer grass samples collected in midsummer in the Waikato district (Jackson et al. 1996) gave composition in terms of protein, soluble sugars, NDF, and organic matter digestibility (%DM) as 19.2, 5.7, 44.2, and 71.2, respectively. The last figure would convert to a DM digestibility of c. 68.5%. It would seem that vegetative summer grass is not markedly different to perennial ryegrass in composition, perhaps lower in protein and soluble sugars, higher in NDF, and similar in DM digestibility during March (Ulyatt et al. 2002). Therefore, the summer grass-dominant pasture in the present study had a composition that was not outside the range of perennial ryegrass-dominant pastures.

There is a convention in international inventory comparisons of expressing methane emission as MY (IPCC 1997). Methane emission parameters from the cows and sheep fed kikuyu grass in 1997 and cows fed summer grass in 2000 were very similar: for cows fed kikuyu grass, sheep fed kikuyu grass, and cows fed summer grass MYs were 7.3, 6.2, and 6.7%, respectively (Tables 4 and 5). The methane emission parameters for kikuyu grass in 1999 were very low and are discussed below. In general the MYs for 1997 and 2000 are somewhat higher than those reported for high quality temperate pastures (Lassey et al. 1997; Ulyatt et al. 2002) and for medium quality alfalfa/grass pastures grazed by steers (range 4.17–4.25; McCaughey et al. 1997), but on average lower than the poor quality alfalfa/grass (7.1) and meadow bromegrass (*Bromus biebersteinii*) (9.5) pastures grazed by lactating beef cows (McCaughey et al. 1999). All other reports of methane emission from C4 pasture plants were made with dried feeds and in calorimetry chambers. Graham (1967) fed sheep three subtropical forages, a legume (*Desmodium uncinatum*) and two grasses (*Sorghum almum* and *Digitaria decumbens* [Pangola grass]), all with a high stem content. The respective values at high intakes for MY were 4.7, 5.3, and 6.9. The value for Pangola grass was similar to those in the present work (Tables 4 and 5), while MYs for the other two forages were similar to the values from temperate forages (Lassey et al. 1997; Ulyatt et al. 2002), although their NDF content was much higher. Margan et al. (1988) measured methane emission from sheep fed the dried leaves of two tropical grasses (*Setaria spacelata* and *Digitaria decumbens*) and the C3 forages perennial ryegrass (*Lolium perenne*) and Persian clover (*Trifolium resupinatum*). At *ad libitum* intakes MYs were 7.3, 7.5, 6.0, and 6.5%, respectively. The MY was higher for the C4 than for the C3 forages. *Bos indicus* cattle were fed *ad libitum* on two tropical grass hays (Angleton grass (*Dicanthium aristatum*) and Rhodes grass (*Chloris gayana*)), a mixture of lucerne hay (*Medicago sativa*), and grain (Kurihara et al. 1999) and MYs were 10.4, 11.4, and 6.7%, respectively. In this case methane emission was clearly much higher for the tropical grasses. It can be argued from the above discussion that methane emission is higher on C4 grasses than C3 forages, however there is high variation and, apart from the results of Kurihara et al. (1999), the argument is not compelling. Causal relationships are not immediately apparent.

Blaxter & Wainman (1964) and Moe & Tyrell (1979) demonstrated a positive relationship between plant cell wall content and methane emission (MY), but this is not strong across all the data sets discussed above where the linear regression was:

MY = 0.054 NDF% + 3.46 (R^2 = 0.19).

Although it is a convention in the international inventory literature (IPCC 1997) to evaluate diets in terms of MY (i.e., the whole diet), in terms of cause it is probably more relevant to compare on the basis of the digestible fraction of the diet, because it is from this fraction that the methane is produced. The simplest fraction to use is the digestible DM (Tables 4 and 5). Methane emitted in g/kg of digestible DM intake (DDMI) in C3 pasture plants was 19.7–26.4 (Lassey et al. 1997), 21.4–29.1 (McCaughey et al. 1997), 46.8–68.7 (McCaughey et al. 1999), 29.7–36.4 (Margan et al.

1988), and 18.0–31.5 (Ulyatt et al. 2002), and for C4 plants was 36.2–41.0 (Graham 1967), 42.1–43.0 (Margan et al. 1988), 60.3–76.4 (Kurihara et al. 1999), and 33.3–38.2 (this paper). This data would suggest that emission (g/kg DDMI) was somewhat higher for the C4 plants. For the very high values of McCaughey et al. (1999) for C3 plants and Kurihara et al. (1999) for C4 plants, the NDF% of the diet was also high at 71.8–75.3. Using the above data, the linear regression of methane emission on NDF% was:

Methane emission (g/kg DDMI) = 0.686 NDF% + 1.294 ($R^2 = 0.48$; $P < 0.01$).

So the relationship between methane emission per unit of digested DM and plant fibre content was positive and significant. It must be noted that this regression was built from sets of data that included both cattle and sheep, some grazing and some housed indoors, and used different techniques to estimate methane emission, feed intake, and digestibility. It does, however, indicate that C4 plants produce more methane per unit of digestible DM than C3 plants, presumably because they contain a higher percentage of cell wall carbohydrates.

In 1999 both the cows and the sheep grazing kikuyu grass had methane emissions that were lower than expected (Tables 4 and 5). Milk yield was also significantly reduced in the dairy cows in 1999, leading to reduced calculated feed intake. The possibility that the batch of SF_6 permeation tubes used in 1999 was not calibrated correctly was not supported by the permeation tube data: the measured pre-experimental permeation rate of the tubes was as expected, as was the behaviour of control tubes from the same batch (Lassey et al. 2001). Further, the same 12 sheep used in the 1999 kikuyu experiment, containing the same permeation tubes, were used 1 month later (March 1999) for methane emission measurements from a ryegrass-dominant pasture in the Manawatu. Methane emission was 19.3 ± 5.4 (SD) g/day, a value that is within the range normally found, which supports the view that the permeation tubes were functioning properly and that the kikuyu grass results in 1999 were real and methane emission was truly depressed. The only major difference in pasture management between the years was the application of urea fertiliser in 1999. The depression was more marked with sheep than cows: MYs for sheep were 6.2 and 1.9% and for cows 7.0 and 3.8% in 1997 and 1999, respectively. The only noticeable difference between sheep and cows in 1999 was in grazing behaviour: the cows grazed evenly right across the paddock leaving quite a high residual, while sheep grazed out small patches almost to ground level. This behaviour was not observed in 1997. It is possible that the 1999 kikuyu grass contained a substance that inhibited methanogenic bacteria in the rumen. There is a condition, "kikuyu poisoning" that is observed sporadically in ruminants grazing kikuyu grass in New Zealand, Australia, and South Africa (Cheeke 1995) which occurs in conditions similar to those observed in the present work. While the pathology of the condition is well documented (Cheeke 1995), its cause is unknown although several suggestions have been made, including mycotoxicoses (Martinovich et al. 1972), factors associated with army worm (*Pseudaletia separata*) infestation of the pasture (Smith & Martinovich 1973), and high concentrations of oxalate in the plant (Peet et al. 1990). In the present work in 1999 there were infestations of army worm within 10 km of the experimental site, though not at the site. This may mean that environmental conditions were suitable for kikuyu poisoning. The grazing behaviour of the sheep in 1999, in grazing patches to ground level, might have enhanced the chance of the sheep consuming fungi, especially saprophytic fungi. None of these possibilities was confirmed in the present work. Both the present work and that of Ulyatt et al. (2002) suggest the possibility that compounds might be produced under certain conditions in pastures that can inhibit methanogenic bacteria in the rumen.

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