METHANE PRODUCTION BY NEW ZEALAND RUMINANTS

A REPORT PREPARED FOR THE MINISTRY FOR THE ENVIRONMENT

BY

DSIR GRASSLANDS

JUNE 1991

METHANE PRODUCTION BY NEW ZEALAND RUMINANTS

THIS IS A REPORT DESCRIBING THE ANNUAL PRODUCTION OF METHANE BY NEW ZEALAND'S GRAZING RUMINANTS IN RELATION TO THEIR SEASONALLY CHANGING DIET

IT IS THE RESULT OF A CONTRACT BETWEEN THE MINISTRY FOR THE ENVIRONMENT AND DSIR GRASSLANDS

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1. *Summary*

Methane production by ruminants in New Zealand (sheep, beef cattle, dairy cattle, goats and deer) was estimated using a mathematical model of rumen digestion (Baldwin *et al.*, 1987) interfaced with estimates of livestock numbers. Input required by the model was diet composition and feed intake.

New Zealand was divided into climatic regions that contained similar pasture species, growth patterns and thus pasture composition. Each region (North, East, Central and South) was classified into **Improved, Unimproved** and **Tussock** grasslands and livestock allocated to these in line with acceptable stocking rates. Models of livestock movements within a year were developed for each animal and land class.

Food dry matter intake for each class of livestock was calculated from estimates of feed requirements and diet digestibility.

Total methane production from ruminants was estimated to be 1.50 Tg per year: 58.4% sheep, 20.7% beef cattle, 17.7% dairy cattle, 2.0% deer and 1.2% goats. There was considerable seasonal variation in methane production in the order Spring > Summer > Autumn > Winter. Dairy farming appears to be more efficient in terms of methane production than sheep or beef farming.

2. *Introduction*

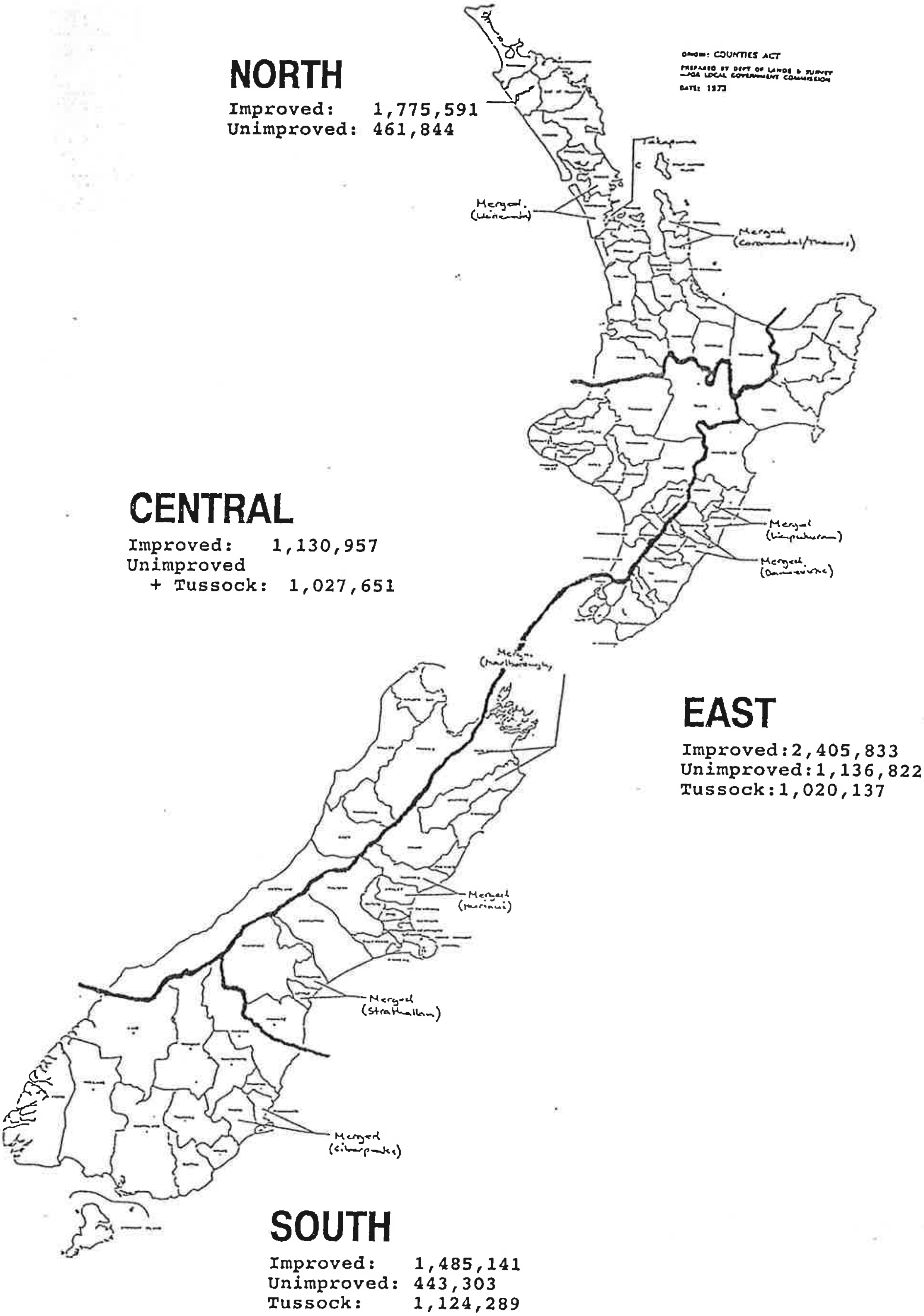
Methane has been identified as a gas which has a 20 year global warming potential 63 times greater than CO_2 per kg of gas (IPCC, 1990). The 1980 concentration of methane in the atmosphere was 1.72 ppmv (compared to 353 ppmv for CO_2), however its rate of increase is about 1.0% per year, being approximately twice that of CO_2 (IPCC, 1990). Atmospheric methane arises from many sources such as land fills, swamps, paddy fields, seepage of natural gas and ruminants, however this report will concentrate on estimating the contribution from ruminants in New Zealand.

Methane is a product of anaerobic fermentation in both the rumen (c.90%) and the caecum (c.10%). Hydrogen ions liberated during the digestion of carbohydrates, proteins and other dietary constituents are utilized by methanogenic bacteria to produce methane. While this process is beneficial in maintaining a satisfactory environment in the rumen it is inefficient in terms of nutrient utilization because approximately 8% of gross energy is lost as methane. Thus while ruminant nutritionists have been interested in methane reduction for many years in terms of efficiency, interest in its reduction for environmental reasons is a reasonably new phenomenon.

The present study was undertaken to try and obtain an accurate estimate of methane production from New Zealand's ruminants. Previous estimates, based on methane production per animal as a % of energy intake, have indicated that total methane production may lie between 1.10 and 1.56 Tg/year (Fennessy, 1989; Lassey *et al*, 1990; Hollinger and Hunt, 1990; G.C. Waghorn, pers. comm.). In the present case, methane was estimated using the mathematical model of ruminant digestion of Baldwin *et al* (1977). The model computes methane production by integrating the stoichiometries of the relevant biochemical reactions occurring in the rumen during the process of food degradation and microbial growth. The

Fig. 1

Geographic Regions into which animals were allocated for the estimation of methane production. Effective grazed areas (ha) are shown.



approach attempts to be mechanistic rather than empirical. The model requires as input the dry matter intake and the chemical composition of the diet consumed by the animal under consideration. The numbers of each class of ruminant livestock and their variation during the year were also required.

3. *Calculation of methane production*

3.1 *Vegetation classes*

The rumen model requires as input data on the chemical composition of the diet. For this reason it was necessary to divide New Zealand into climatic regions that contained similar pasture species, growth patterns and thus pasture composition. These areas were defined (Fig. 1) as *North* (characterised by warm summers, mild winters and an even distribution of rainfall through the year), *East* (dry summers with mild to cold winters), *Central* (mild winters and mild summers with even rainfall distribution), and *South* (cold winters, mild summers with even rainfall distribution). Within each of these regions land was classified as *Improved*, *Unimproved* and *Tussock* (Appendix 1) by combining vegetational cover data (Newsome 1987) with the Local Territorial Authority Boundaries extracted from the DSIR Land Resources Geographic Information System database. This output defined areas for each of the three vegetation classes within the 103 county/urban regions defined by the Department of Statistics. Livestock were distributed to land class within each of the 103 statistical districts and these numbers were in turn aggregated into 22 geographic zones which were then converted to the four major geographic regions (Fig. 1). Table 1 gives the 10 final aggregations of land class x region.

Table 1. The ten land classes used to indicate pasture growth regions in New Zealand.

	North	East	Central	South
Improved	x	x	x	x
Unimproved	x	x	x	x
Tussock	-	x	-	x

3.2 *Livestock numbers*

Animal data from the New Zealand department of Statistics 30 June 1990 census were used, totalling 57,852,192 sheep, 4,600,703 beef cattle, 3,463,802 dairy cattle, 1,062,900 goats and 976,290 deer. Feral deer and goats were estimated (Dr J Parkes, Forest Research Institute) to be 250,000 and 587,000 (including 50,000 Thar/Chamois) respectively. Feral animals were each treated separately from farmed animals.

Census data were classified into **Breeding stock** and **Other livestock** for sheep, beef and dairy. Only 'total' numbers were available for deer and goats. Fourteen classifications (see Appendix 2) within each of the geographic zones detailed the number of each animal species on different **Farm types.**

Livestock were allocated to land classes to reflect typical farming practices within constraints of acceptable stocking rates for each land class. An example of this procedure, as used in the Northland zone is presented in Appendix 2. As the areas of tussock in the North and Central regions were small, no animals were allocated to this class, but instead to unimproved land.

A model was constructed for each animal type on each of the 10 geographical and vegetation classes. The model described the movement of animals within a year and included transfers due to birth, slaughter and age. Assumptions made in developing the models are given in Appendix 3. One of the models (sheep for East improved grassland) is given as an example in Appendix 4.

When interfacing livestock numbers with the model it was calculated that 2060 model runs would be required to estimate methane production for all livestock classes, all land classes and for every month of the year. It was decided that little reduction in accuracy would result from calculating on a seasonal rather than a monthly basis and this aggregation reduced the number of model runs to 560. Seasons are therefore defined as Winter (~~January~~, June July, August), Spring (September, October, November), Summer (December, January, February) and Autumn (March, April, May).

3.3 *Estimation of food dry matter intake (DMI)*

Intakes of the various classes of animals were derived on a monthly basis using the equation:

DMI = R/NV

The feed requirements (R; MJME/d) of every class of animal were obtained by assuming average liveweight change curves for mature females or liveweight gain curves for growing and fattening stock (Scott *et al*, 1980). ME is metabolisable energy. From these curves were obtained requirement allowances for maintenance, growth, pregnancy or lactation calculated for New Zealand conditions for sheep and cattle (Ulyatt *et al*, 1980), deer (Fennessy and Milligan 1987) and goats (McCall and Lambert 1987). Nutritive values (NV; MJME/kg DM) were either taken from published values (e.g. Ulyatt *et al*, 1980) or calculated from the equation:

NV = GE x DE x (ME/DE)

Where GE (gross energy) was assumed to be 17.57 MJ/kg DM, DE (proportion digested) was a variable and ME/DE was 0.80. NV was thus determined by digestibility which was estimated on a monthly basis, for each type of animal, on each land class within each region. An example of a set of calculations for a mature dairy cow in the North improved land class is given in Appendix 5. It was assumed that the food selected and consumed by the animals was of 2% higher digestibility than the pasture available. Allowance was made for standard management practices, e.g., beef cattle were used to clean up summer, autumn and winter pastures by forcing them to eat material that had seeded or was dead. Food intakes were aggregated into seasonal means.

3.4 Food composition

The rumen digestion model of Baldwin *et al*, (1977) requires that food composition be specified in terms of 13 main components: soluble carbohydrates, organic acids, pectin, starch, lipid, cellulose, hemicellulose, soluble protein, insoluble protein, non-protein nitrogen, lignin, soluble ash and insoluble ash. Data was assembled from a number of published and unpublished sources and an average composition was specified for each of the major classes of pasture species for spring, summer, autumn and winter. Improved pastures were assumed to be mixtures of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) while unimproved and tussock grazing were assumed to be mixtures of browntop (*Agrostis tenuis*), white clover and dead matter. It was also assumed that during winter dairy cows consumed a mixture of 60% improved pasture, 20% silage and 20% hay (AM Bryant, pers. comm). In the absence of any data, dead matter was assumed to have the same chemical composition as barley straw.

All these components of the diet were individually entered into the rumen model and methane production predicted. When the two grasses, perennial ryegrass and browntop, were tested over the four seasons it was found that the only significant difference occurred in summer composition. For this reason a mean composition was taken for each grass for spring, autumn and winter and designated "other" (Appendix 6). White clover did not differ significantly between seasons in composition or methane production. Compositions of the individual components of the diet are given in Appendix 6.

The botanical composition of the pastures and therefore the composition of the dry matter consumed are known to vary with season, although the data available are both variable and unreliable. This is partly because the techniques used to measure pasture growth and composition do not necessarily reflect the composition of pasture available to the grazing animal, and partly because measuring diet selection with animals is very difficult. To try and overcome these problems pasture compositions chosen for simulation studies were based on the authors' experience and by consultation with other scientists experienced in this area. Various mixtures of pasture components were chosen to represent pasture selected during the seasons of the year. Some examples of these are given in Appendix 7.

3.5 *Rumen digestion model*

The mathematical model used to predict methane production in the rumen (Baldwin *et al*, 1977; Murphy *et al*, 1986; Baldwin *et al*, 1987) requires the intake of the 13 main chemical components to be specified. The model predictions are based on known stoichiometries of food degradation and microbial growth. The relatively large number of chemical components are necessary because they either produce unique stoichiometries or affect the physico-chemical milieu in the rumen. Fortunately, one of the authors (MJU) was

Fig. 2

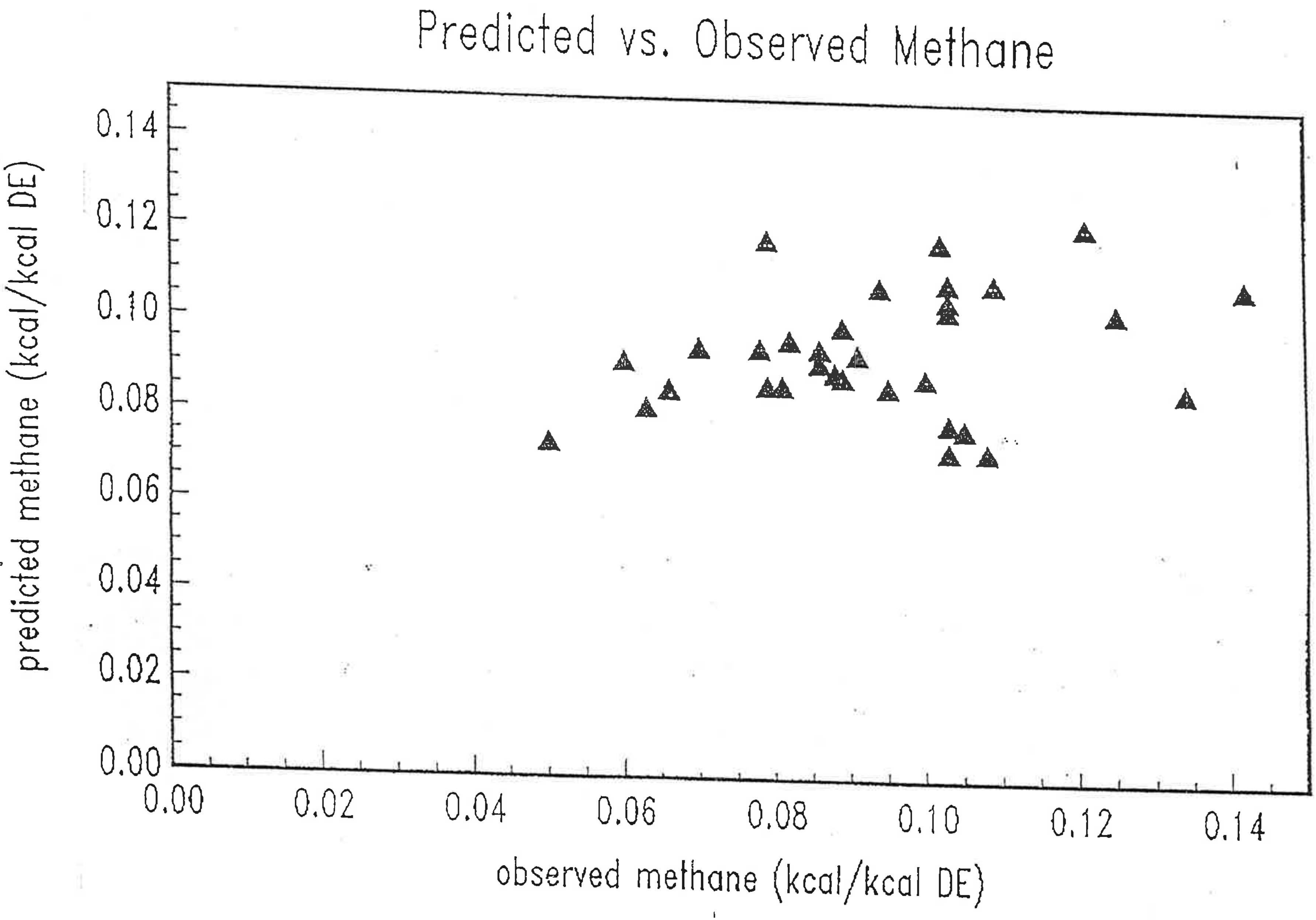

Predicted vs. Observed Methane
predicted methane (kcal/kcal DE)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
observed methane (kcal/kcal DE)

Fig. 3

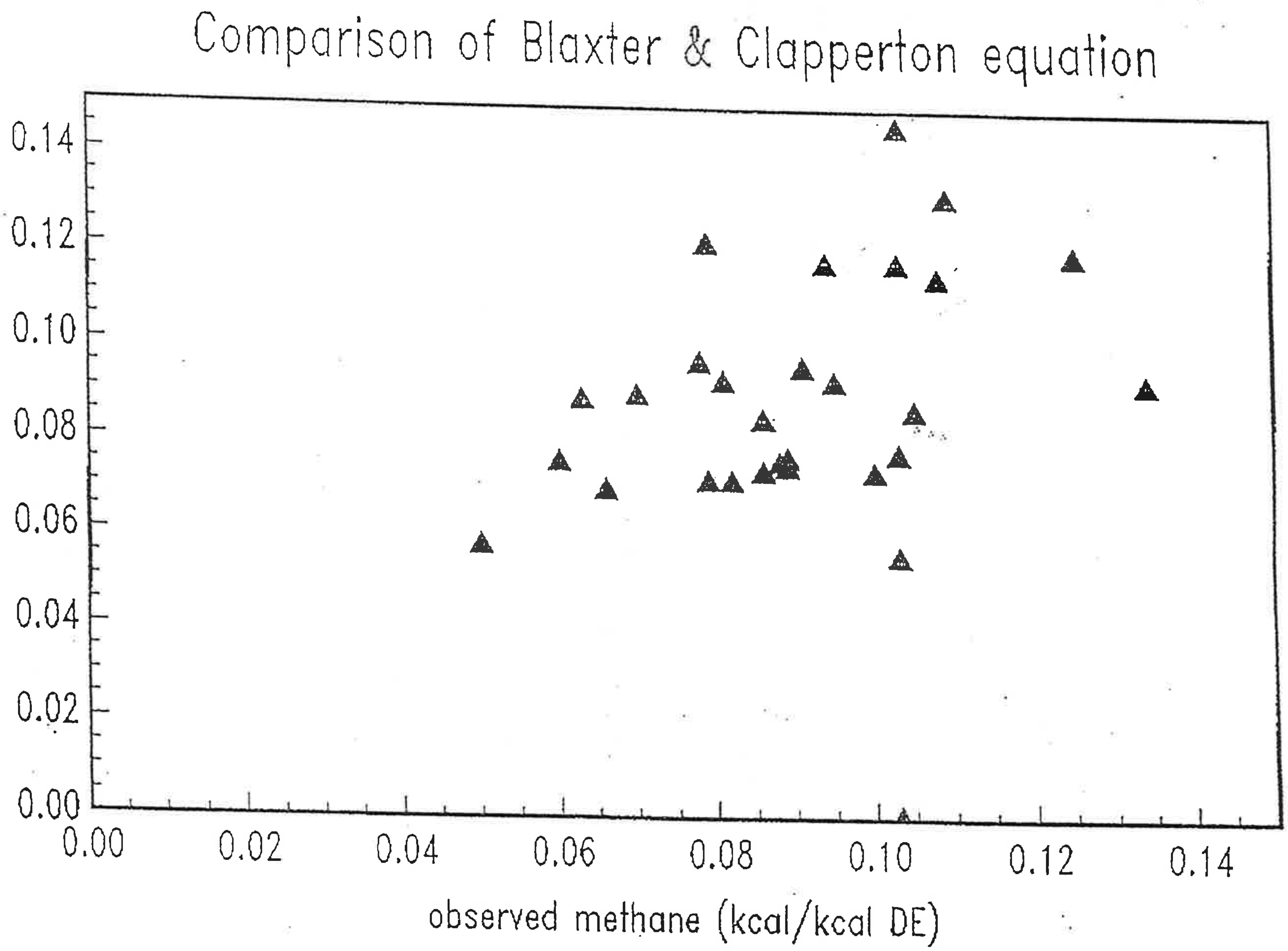

Comparison of Blaxter & Clapperton equation
B & C predicted methane
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
observed methane (kcal/kcal DE)

Fig. 4

Comparison of Moe & Tyrrell equation

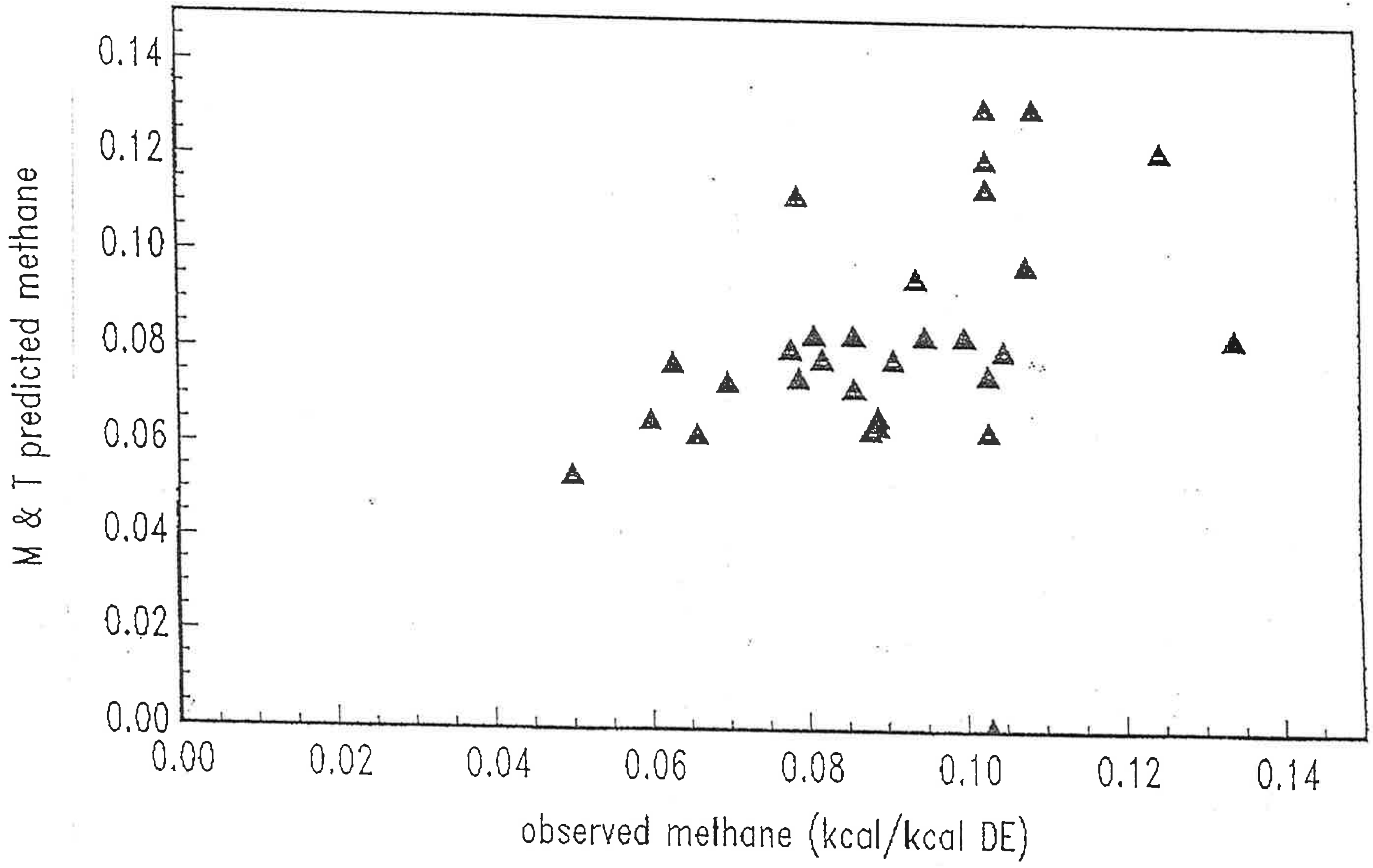
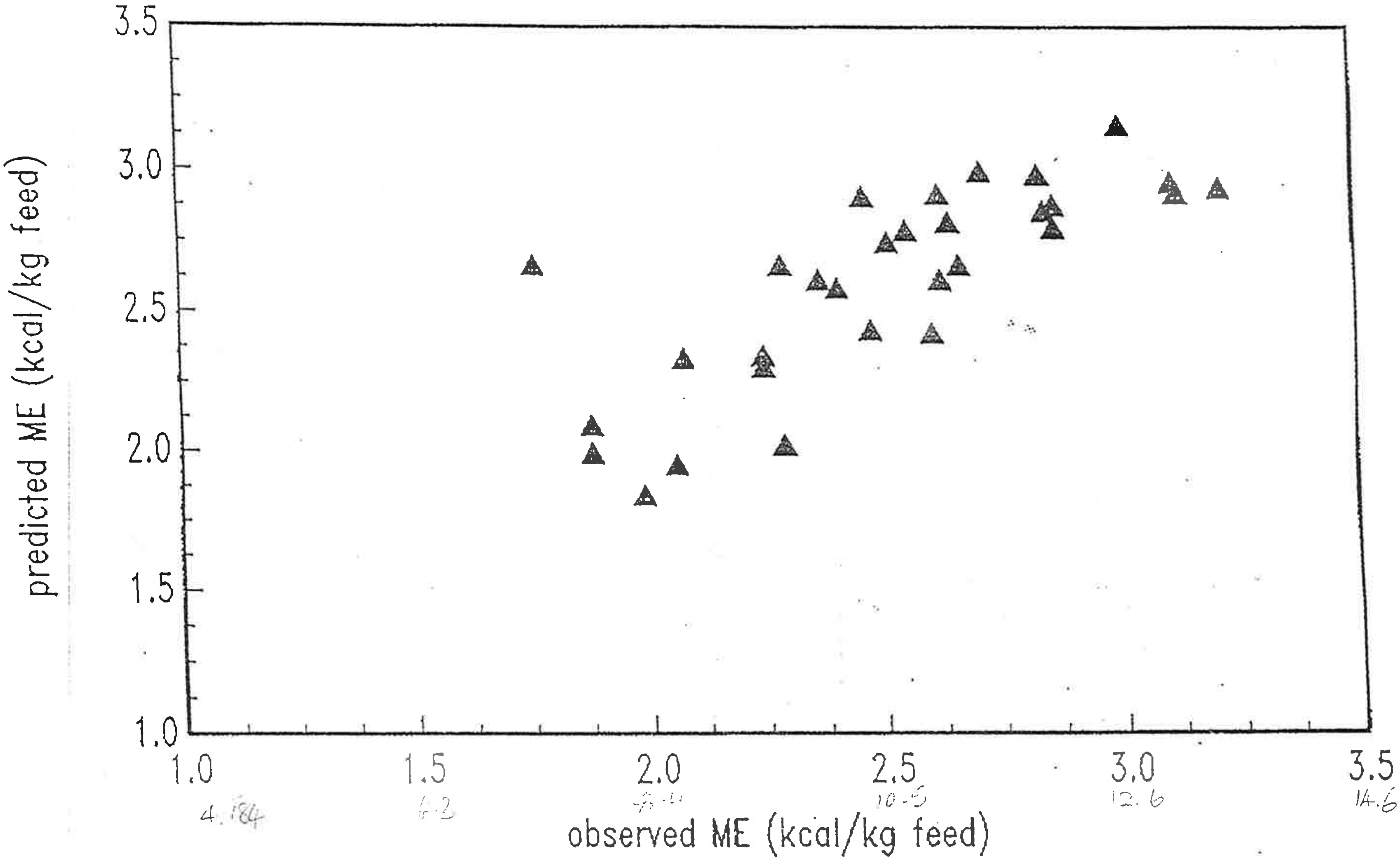


Fig. 5

Predicted vs. Observed Metabolizable Energy



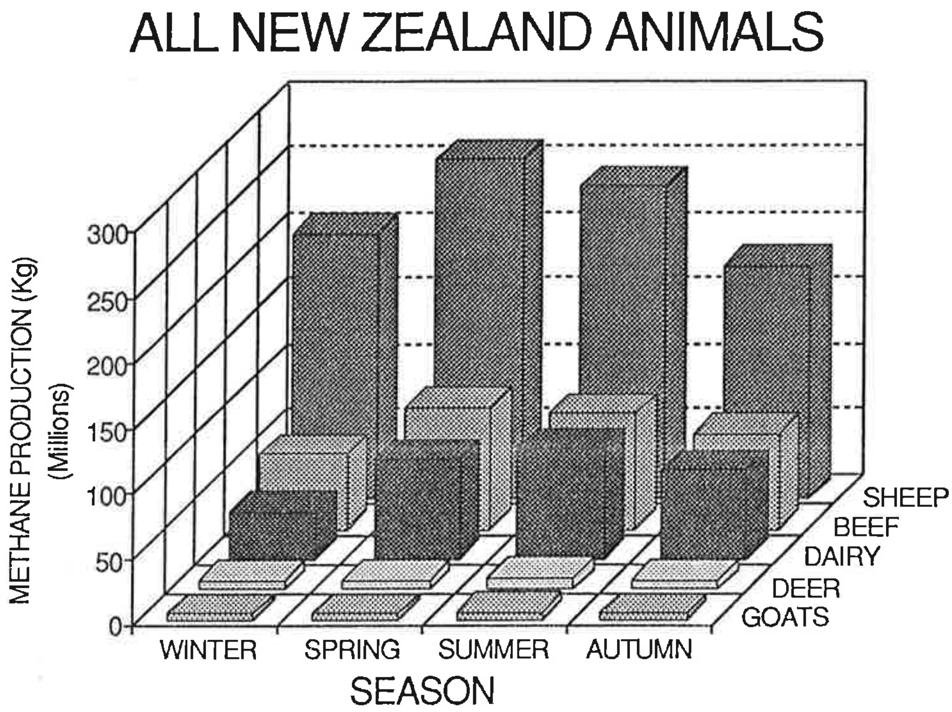
involved in the model development and so appropriate compositional data were available for New Zealand diets (Appendix 6).

The accuracy of the model in predicting both methane production and digestion in general needs examining. A test set of data was taken from the literature, where animals were fed a wide range of diets of differing composition and food intake and methane production were measured. These data were used to test the model's ability to predict methane. Fig. 2 presents a plot of methane production predicted by the rumen model plotted against values observed in the test data. Figs. 3 and 4 present similar comparisons where methane was predicted by the equations of Blaxter and Clapperton (1965) and Moe and Tyrrell (1979). The latter two equations are commonly used to predict methane production. (Note: the authors apologise for the units used, however, these do not influence the comparisons). There is a bias in the model predictions: predictions are high at low observed methane and low at high observed methane. Statistical analysis of all predictions showed that when residuals were plotted against predicted methane, there was more bias with the Blaxter and Clapperton (1965) and Moe and Tyrrell (1979) predictions than the rumen model predictions. However, the methane production values generated by the model for the New Zealand diets (which are all high quality) fall between 0.09 and 0.11 kcal/kcal DE, the region where the model predictions are most accurate.

Model prediction of metabolisable energy/kg feed is compared with observed values in Fig. 5, showing that the model predicts overall digestion very well (r^2 = 0.99).

The rumen model was not originally developed to predict methane production. It is currently being refined at the University of California, Davis to better represent methane production.

Fig. 6


ALL NEW ZEALAND ANIMALS
METHANE PRODUCTION (Kg)
(Millions)
300
250
200
150
100
50
0
WINTER
SPRING
SUMMER
AUTUMN
SEASON
SHEEP
BEEF
DAIRY
DEER
GOATS

4. *Methane production by ruminants in New Zealand*

4.1 *Total methane production*

Total methane production in the current exercise was calculated to be 1.50 Tg/year (Table 2). This is within the range of values calculated by other methods (Fennessy 1989; Lassey *et al*, 1990; Hollinger and Hunt, 1990; Waghorn, pers. comm.). We believe our estimates are [at the high end of the range] higher because our data on livestock numbers throughout the year are more accurate than those used in other studies.

Table 2. Seasonal methane production by ruminant animals in New Zealand (tonnes x 10^3).

SEASON	DAIRY	SHEEP	BEEF	DEER	GOAT	TOTAL
WINTER	36.9	202.0	57.1	6.7	4.2	306.9
SPRING	76.3	258.3	93.7	7.1	4.1	438.5
SUMMER	84.5	238.0	87.8	9.2	4.8	424.3
AUTUMN	68.4	177.9	72.8	6.9	4.4	330.4
TOTAL	266.0	876.2	310.3	29.9	17.5	1,500.1
Implied EF (kg/yr) →	76.8	15.1	67.4	30.6[1] 24.4[2]	16.5[1] 10.6[2] 7.5	

4.2 *Seasonal variation in methane production*

Table 2 shows that there were considerable seasonal differences in methane production in the order Spring > Summer > Autumn > Winter. This is predominantly a reflection of animal numbers and the increased food intake associated with lactation. There was some difference between animal species, with peak methane production occurring in summer for dairy cattle, deer and goats and in spring for sheep and beef cattle. Seasonal variation is presented in graphical form in Fig. 6.

1 On the basis that all CH_4 is calculated as produced by farmed deer/goats (believed wrong)

2 On the basis that all CH_4 is calculated from farmed + feral deer/goats (believed correct)

Fig. 7

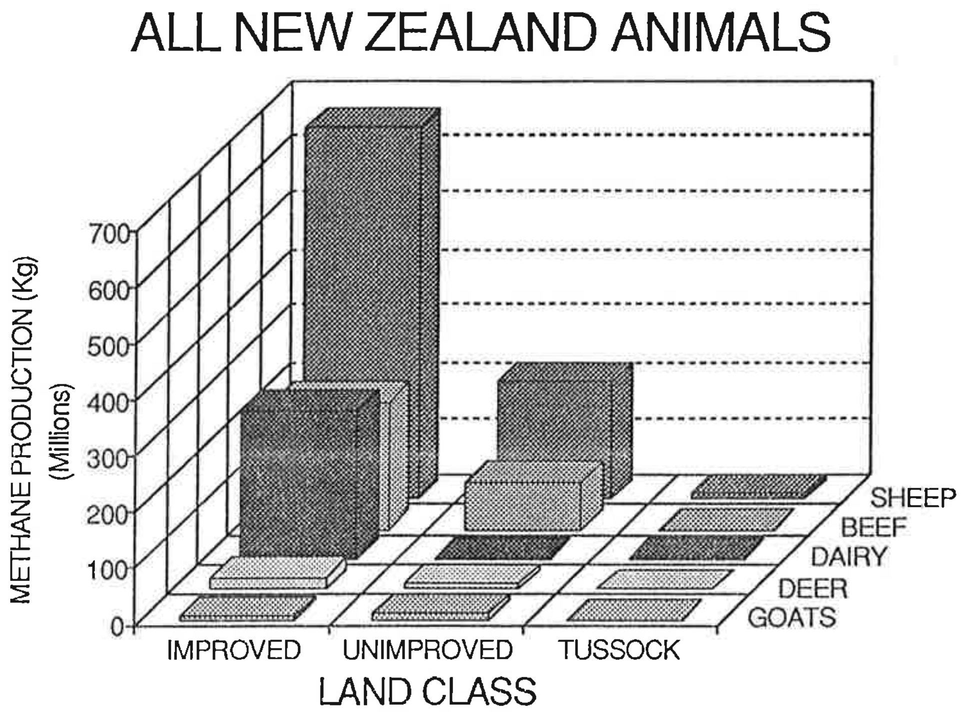
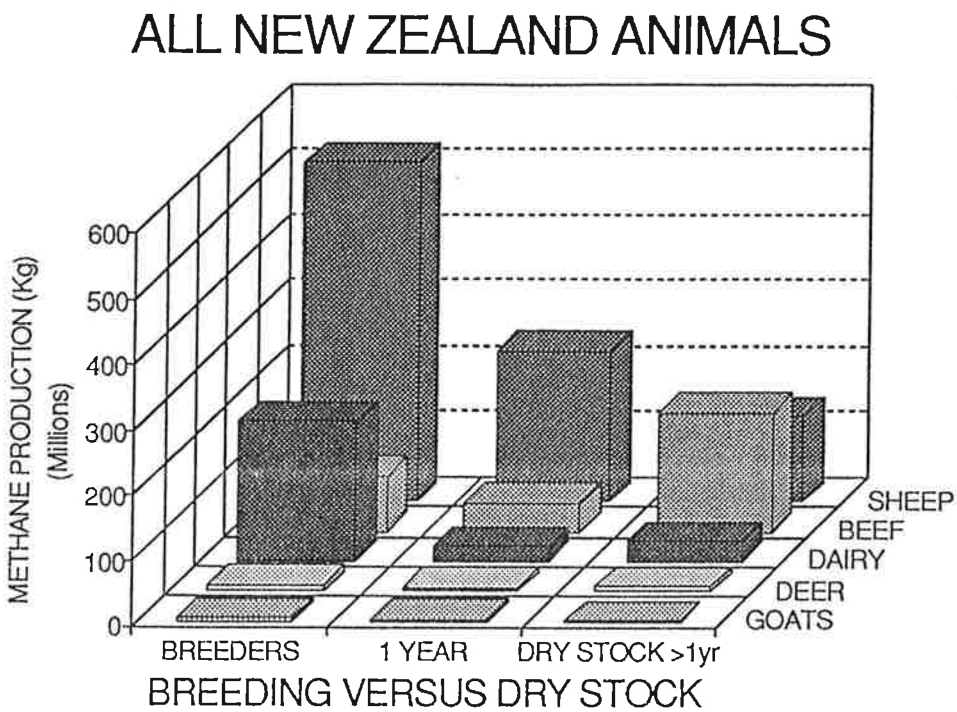

ALL NEW ZEALAND ANIMALS
METHANE PRODUCTION (Kg)
(Millions)
0
100
200
300
400
500
600
700
SHEEP
BEEF
DAIRY
DEER
GOATS
IMPROVED
UNIMPROVED
TUSSOCK
LAND CLASS

Fig. 8


ALL NEW ZEALAND ANIMALS
METHANE PRODUCTION (Kg)
(Millions)
600
500
400
300
200
100
0
SHEEP
BEEF
DAIRY
DEER
GOATS
BREEDERS
1 YEAR
DRY STOCK >1yr
BREEDING VERSUS DRY STOCK

4.3 *Variation between animal species in methane production*

There was considerable variation between species in methane production (Table 2). Sheep produced 58.4% of total methane followed by beef cattle (20.7%), dairy cattle (17.7%), deer (2.0%) and goats (1.2%). This result can also be seen graphically in Fig. 6.

4.4 *The contributions of farming type to methane production*

The two main farming systems used in New Zealand are mixed sheep with beef, and dairying. On this basis the sheep and beef systems produced considerably more methane than did dairying (Table 2, Fig. 6).

4.5 *The contribution of land class to methane production*

Improved land accounted for the largest portion of methane production, followed by unimproved land with a minor contribution from tussock (Fig. 7). This distribution occurs because improved land is the largest land class and because stocking rate was higher on improved land. In other words, it was largely a reflection of animal numbers.

4.6 *Methane production from breeding versus dry stock*

Fig. 8 demonstrates that breeding stock produced most methane. The only exception on an animal species basis was with beef cattle where fattening stock produced more methane than breeding stock. This is due to animal numbers and is reinforced by the fact that a large proportion of male dairy calves are transferred into beef farming. Breeding stock had a high methane output because of their increased food intakes during late pregnancy and lactation.

5 Conclusions

5.1 Reliability of the model estimates of methane production

The quality of the data used in the study was variable. The data on livestock numbers and their changes through the year are accurate. New Zealand collects and processes agricultural statistics annually, something that very few countries do. Our colleagues in the US, who are working on similar data to predict global methane from ruminants believe the New Zealand livestock data are the best in the world. This is important because livestock numbers are probably the most significant determinant of total methane production.

The animal requirements for nutrients used in this study, derived from Ulyatt *et al*, (1980), McCall and Lambert (1987) and Fennessy and Milligan (1987), are based on experimental data and are regarded by the authors as being accurate for New Zealand's pastoral agricultural system.

The data on the chemical composition of pasture species and other diets have also been derived experimentally under New Zealand conditions and are regarded as being adequate.

Estimates of the digestibilities of pastures were required to predict food intake. As few NZ measurements of digestibility are available for the wide range of pastures used for the various land classes and regions, many values had to be estimated.

Similarly, the botanical composition of the pasture selected by the animals had to be estimated due to the extremely small amount of experimental data available. The available data suggest that animals select food that is of much higher quality than that on offer. This argument applies to digestibility as well as the chemical composition of the diet selected.

Finally, the rumen model is itself still being evaluated for its accuracy in predicting methane. Its accuracy will almost certainly improve as the model is refined.

Given the caveats stated above, we believe the data presented in this study to be a good approximation of methane production by ruminants in New Zealand although sensitivity analyses are still required to refine the estimates. All previous estimated values are based on the assumption that methane production is 6 to 8.5% of gross energy intake. The model predicts methane from biochemical transactions and is thus a totally different approach. The fact that both methods give similar predictions gives us confidence in our predictions.

5.2 *Methods for reducing methane production from ruminants*

Generally we agree with the options reported by IPCC (1990). Other than reducing livestock numbers, an option that is politically and economically unsustainable in New Zealand, most promise would appear to be in the area of improving the efficiency of our pastoral systems. Supplementation, use of feed additives to modify rumen microflora and the use of hormones such as bST are theoretical possibilities but these have limitations such as the cost and efficacy of application in a low-cost pastoral environment. bST has the added problem of consumer acceptance. However any methods that increase the intake of digestible nutrients per animal and thus lower the proportion of the diet that is used for maintenance will result in increased food conversion efficiency and lowered methane. In particular, research should be conducted into methods of altering pasture quality to increase intake.

The FOB values for all sheep, beef and dairy products in 1989/90 were $B3.513, $B1.370 and $B3.906 respectively (NZ Meat and Wool Board's Economic Service). In terms of methane production per dollar earned sheep, beef and dairy cattle were 0.249, 0.227 and 0.068 (kg/$) respectively. In other words dairying was approximately 3.5 times more methane-efficient than sheep or beef farming in 1989/90. There is considerable scope for improvement with sheep and beef farming.

5.3 *Global estimates of methane production*

Many estimates of global methane production from ruminants have been made (e.g. Reuss *et al*, 1988; IPCC, 1990). In our view these tend to be low because estimates of livestock numbers and requirements are very poor for many countries. These estimates contrast with those from New Zealand which indicate relatively high values. It would be unfortunate if New Zealand were penalised because its estimates were high but accurate, compared to other countries whose estimates were low but very bad. We should not be penalised for being accurate.

Similarly, ruminant methane production per head of NZ human population calculated from the present study was 438 kg. However, we export approximately 80% of our ruminant-based products. We would argue that our population base should be expanded at least five times to account for all the consumers of our products. On this basis methane production would be 88 kg per head of population per year. No data are yet available to describe methane production from ruminant faeces. In the NZ environment this is likely to be substantially less than in the northern hemisphere where animal waste is collected and stored for long periods allowing anaerobic fermentation to proceed.

6. *Acknowledgements*

Mr R. Tass, NZ Department of Statistics, Auckland, for supplying animal census data.

Dr I. Brookes, Animal Science Department, Massey University, for advice in developing the animal numbers model.

Dr M.G. Lambert and Mr D.A. Clark, DSIR Grasslands, Palmerston North, for helpful discussion on the composition of New Zealand pastures and dietary selection of animals.

Mr R. Davidson and Mr B. Spiers, NZ Meat and Wool Board Economic Service, for providing general statistics and advice on age and sex structure of livestock systems.

Mr P. van der Logt, MAF Policy, Wellington, for providing statistics of animal slaughtering at abattoirs and meat export companies in New Zealand.

NZ Deer Farmers Association, Wellington, for advice on deer farming statistics.

Drs M.T. Jasen and P.F.J. Newsome, DSIR Land Resources, Lower Hutt, and G.R. Harmsworth, DSIR Land Resources, Palmerston North for providing Land Class classification data for each county.

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