Estimates of enteric methane emissions from cattle in Canada using the IPCC Tier-2 methodology

K. H. Ominski[1], D. A. Boadi[2], K. M. Wittenberg[1], D. L. Fulawka[1], and J. A. Basarab[3]

[1]*Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2;* [2]*Canadian Food Inspection Agency, Ottawa, Ontario, Canada K1A 0Y9;* [3]*Alberta Agriculture, Food and Rural Development, Western Forage Beef Group 6000 C&E Trail, Lacombe, Alberta, Canada T4L 1W1.*
Received 24 November 2006, accepted 28 March 2007.

Ominski, K. H., Boadi, D. A., Wittenberg, K. M., Fulawka, D. L. and Basarab, J. A. 2007. **Estimates of enteric methane emissions from cattle in Canada using the IPCC Tier-2 methodology**. Can. J. Anim. Sci. **87**: 459–467. The objective of this study was to estimate enteric methane (CH_4) emissions of the Canadian cattle population using the International Panel on Climate Change (IPCC) Tier-2 methodology. Estimates were then compared with IPCC Tier-1 methodology and data from Canadian research studies (CRS). Animal inventory data for the Canadian beef and dairy cattle herd was obtained from Statistics Canada. Information on cattle performance and feeding practices were obtained from provincial cattle specialists via a survey, as well as various published reports. Methane emissions from dairy and beef cattle in Canada for 2001 were 173 030 t yr^{-1} or 3.6 Mt CO_2 eq. and 763 852 t yr^{-1} or 16.0 Mt CO_2 eq., respectively, using Tier-2 methodology. Emissions for dairy cattle ranged from 708 t yr^{-1} in Newfoundland to 62 184 t yr^{-1} in Ontario. Emissions for beef cattle ranged from 191 t yr^{-1} in Newfoundland to 356 345 t yr^{-1} in Alberta. The national emission factors (kg CH_4 yr^{-1}) using IPCC Tier-2 were 73, 126, 90, 94, 40, 75, 63 and 56 for dairy heifers, dairy cows, beef cows, bulls, calves < 1yr, beef heifer replacements, heifers > 1 yr, and steers > 1yr, respectively. Emission factors (kg CH_4 yr^{-1}) for the above classes of cattle using IPCC Tier-1 were 56, 118, 72, 75, 47, 56, 47 and 47, respectively. The values were 15.1% higher to 25.3% lower than those obtained using IPCC Tier-2 methodology. When IPCC Tier-2 emission factors were compared with CRS, they were 12.3% lower to 32.6% higher than those obtained using the Tier-2 methodology. In conclusion, national estimates of enteric emissions from the Canadian cattle industry using Tier-1 and Tier-2 methodologies, as well as CRS, differ depending on the methodology used. Tier-2 methodology does allow for the inclusion of information other than population data, including feeding strategies, as well as duration of time in a given production environment. Additional research is required to establish the extent to which feed energy is converted to methane for those production scenarios for which there is no published data.

Key words: IPCC Tier-2, IPCC Tier-1, enteric fermentation, cattle, methane, emission factor, methane conversion rate

Ominski, K. H., Boadi, D. A., Wittenberg, K. M., Fulawka, D. L. et Basarab, J. A. 2007. **Meilleure estimation des émissions de méthane intestinal par les bovins canadiens grâce à la méthode de niveau 2 du GIEC**. Can. J. Anim. Sci. **87**: 459–467. L'étude devait estimer les émissions de méthane intestinal (CH_4) du cheptel bovin canadien par la méthode de niveau 2 du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC). Les auteurs ont comparé ces estimations à celles obtenues avec la méthode de niveau 1 et les données tirées des études canadiennes. Les données relatives au cheptel canadien de bovins laitiers et de bovins de boucherie venaient de Statistique Canada. L'information sur le rendement des animaux et les pratiques d'élevage a été recueillie des zootechniciens provinciaux interrogés et de divers rapports. Selon la méthode de niveau 2, en 2001, les bovins laitiers et de boucherie canadiens libéraient 173 030 t (équivalent de 3,6 Mt de CO_2) et 763 852 t de méthane (équivalent de 16,0 Mt de CO_2) par année, respectivement. Les émissions des bovins laitiers variaient de 708 t par année, à Terre-Neuve, à 62 184 t par année, en Ontario. Celles des bovins de boucherie fluctuaient de 191 t par année, à Terre-Neuve, à 356 345 t par année, en Alberta. Toujours selon la méthode de niveau 2 du GIEC, les facteurs d'émission nationaux (kg de CH_4 par année) s'établissaient respectivement à 73, 126, 90, 94, 40, 75, 63 et 56 pour les génisses laitières, les vaches laitières, les vaches de boucherie, les taureaux, les veaux de moins d'un an, les génisses de boucherie de remplacement, les génisses de moins d'un an et les bouvillons de moins d'un an. Avec la méthode de niveau 1, les facteurs d'émission (kg de CH_4 par année) des mêmes types de bovins se chiffraient respectivement à 56, 118, 72, 75, 47, 56, 47 et 47. Ces valeurs sont de 15,1 % supérieures à 25,3 % inférieures à celles obtenues avec la méthode de niveau 2. Lorsqu'on compare les facteurs d'émission calculés avec la méthode de niveau 2 du GIEC à ceux mentionnés dans les études canadiennes, on constate que les seconds sont de 12,3 % plus faibles à 32,6 % plus élevés que les premiers. Les auteurs en concluent que l'estimation des dégagements entériques par l'industrie canadienne de l'élevage varie avec la méthode employée, à savoir celle de niveau 1 du GIEC, celle de niveau 2 ou celles des études canadiennes. La méthode de niveau 2 permet toutefois d'inclure d'autres paramètres que la population, notamment les stratégies d'engraissement ainsi que le laps de temps passé dans un milieu donné. Il faudrait entreprendre d'autres recherches pour préciser dans quelle mesure l'énergie des aliments est convertie en méthane pour les méthodes de production sur lesquelles on n'a encore rien publié.

Mots clés: Méthode de niveau 2 du GIEC, méthode de niveau 1 du GIEC, fermentation intestinale, bovins, méthane, facteur d'émission, taux de conversion en méthane

Abbreviations: **CH_4**, methane; **CO_2 eq.**, carbon dioxide equivalents; **CRS**, Canadian research studies; **GE**, gross energy; **GEI**, gross energy intake; **GHG**, greenhouse gas; **EF**, emission factor; **IPCC**, International Panel on Climatic Change; **Mt**, megatonnes; **Y_m**, methane conversion rate

Canada's greenhouse gas emissions (GHG) from anthropogenic sources were 720 megatonnes of carbon dioxide equivalent (Mt CO_2 eq.) in 2001, an increase of 18.5% from emissions in 1990 (Olsen et al. 2003). This same report indicates that the agricultural sector in Canada was responsible for 8.3% of total GHG emissions in 2001, with livestock responsible for 48% of this total, of which 31% is attributed to methane (CH_4) emissions from enteric fermentation (Olsen et al. 2003).

Currently, national inventories of CH_4 emissions from enteric fermentation are estimated using the International Panel on Climatic Change (IPCC) Tier-1 methodology, which calculates CH_4 emissions for each animal category by multiplying the animal population by the average emissions factor associated with the specific animal category (IPCC 1997). Weight, age, gender and feeding systems are assumed to be similar within animal category. Using these estimates, it has been determined that Canadian cattle account for 97% of total livestock enteric CH_4 emissions, with 25% attributed to dairy and 72% of emissions coming from beef cattle (Janzen et al. 1998).

It is important to note that this method of calculating enteric emissions does not account for differences in animal management, including feeding strategy or time in a given production environment. According to IPCC (2000), countries using an IPCC Tier-2 methodology can improve emission estimates and reduce uncertainties as this methodology considers a number of variables influencing enteric CH_4 emissions, including weight, age, gender and feeding systems. As with Tier-1 methodology, emission estimates can be calculated on a national or regional basis, but accurate information regarding animal population, as well as management is required, as demonstrated by Basarab et al. (2005). As enteric fermentation is a key source of GHG emissions by the agricultural sector in Canada, adopting the IPCC Tier-2 methodology will improve our ability to determine the mitigation value of various on-farm practices. Several countries, including the United States and Australia, are already using Tier-2 methodology.

The objectives of this study were to estimate enteric CH_4 emissions from Canadian cattle population for year 2001 using the IPCC Tier-2 methodology and further, to compare these values to emission factors generated by the IPCC Tier-1 methodology and Canadian research studies (CRS).

MATERIALS AND METHODS

Characterization of the Canadian Cattle Population

Use of IPCC Tier-2 methodology requires information such as annual populations and feed intake estimates (IPCC 2000). In order to apply these equations to the Canadian cattle population, it was first necessary to characterize the cattle industry in terms of: (i) the population of animals in each of several distinct categories, and (ii) the production practices utilized on-farm, as well as the resulting animal performance.

Cattle Population

Population data for beef and dairy cattle were obtained from Statistics Canada (2003), which conducts bi-annual (January/July) telephone surveys of agricultural producers. Cattle inventories for January to June 2001 were obtained for each province from the 2001 Jul. 01 report. Inventories for July to December for each province were obtained from the 2002 Jan. 01 report (Statistics Canada 2003). These values were averaged to obtain population data for each of the following categories: dairy heifer replacements (female dairy animals greater than 12 mo of age to age at first calving); dairy cows (female dairy animals that have produced a calf); beef cows (female beef animals that have produced a calf); bulls (all male beef and dairy animals over 12 mo of age that are held for breeding purposes); calves (all beef and dairy animals under 12 mo of age); beef heifer replacements (female beef animals greater than 12 mo of age to age at first calving); beef heifers (female beef animals over 12 mo of age that are held for purposes other than reproduction) and beef steers (male beef animals over 12 mo of age that are held for purposes other than reproduction), as described in Table 1. The population of beef and dairy replacement heifers less than 12 mo of age were determined by multiplying the replacement rate for beef and dairy cows obtained for each province by the respective cow population. An estimate of the total replacement heifer population was made by adding these values together. The number of total replacement heifers was then subtracted from the total number of calves less than 12 mo of age to estimate the number of calves backgrounded or sent directly to feedlot.

Cattle Performance and Production Practices

A survey posing questions regarding dairy and beef performance, production and feeding practices was created and administered to cattle specialists who were identified at the regional and/or provincial level in each province. When available, data from producer surveys were utilized to describe the production environment and associated performance of the eight classes of cattle described above. Additional information was sought from personal communication with research scientists at universities or federal research institutions, as well as from provincial or national commodity groups. Performance data collected by provincial or regional recording organizations such as Western Canadian Dairy Herd Improvement Services (WCDHIS 2002) and Ontario Dairy Herd Improvement Services (ODHIS 2003) were utilized.

The survey and published reports provided information for 2001 in the following areas: average body weight, mature weight, daily gain, weight loss during early lactation, milk production, milk fat content, duration and type of production environment (pasture vs. confinement), calving interval, pregnancy rates, replacement rates, age and weight at weaning, type and quality of feed fed at each stage of production, as well as the ratio of steers and heifers sent to feedlot versus those backgrounded. When not provided by the survey data, DE values of the feedstuffs were obtained from the published literature or National Research Council (NRC 2001). The animal performance information that was pro-

Table 1. Cattle and calves on farm by province[z] for 2001 ('000 head)[y]

Categories	BC	AB	SK	MB	ON	QC	NF	NB	NS	PEI
Dairy										
Heifers	35.00	37.50	13.75	19.25	198.50	179.00	1.45	9.50	11.45	6.95
Cows	73.75	91.50	29.00	42.25	366.00	413.50	4.70	19.10	23.95	14.55
Beef										
Cows	284.00	2 009.50	1 230.00	547.00	377.00	209.50	0.65	20.45	26.20	13.35
Bulls	16.25	106.00	60.00	26.00	24.25	14.90	0.10	1.30	1.50	0.80
Calves	230.00	2 063.00	1 013.00	488.00	632.80	378.00	2.00	25.90	30.40	20.50
Heifer replacements	50.50	310.00	192.50	78.50	78.50	33.00	0.30	4.60	5.10	3.10
Heifers > 1yr	15.50	665.00	41.50	54.50	149.50	19.50	0.10	4.10	3.40	9.10
Steers > 1yr	37.50	880.00	79.00	79.50	251.50	75.60	0.20	6.40	5.50	16.70

[z]BC = British Columbia; AB = Alberta; SK = Saskatchewan; MB = Manitoba; ON = Ontario; QC = Quebec; NF = Newfoundland; NB = New Brunswick; NS = Nova Scotia; PEI = Prince Edward Island.
[y]Numbers are an average of the July 2001 and January 2002 provincial inventory. Source: Statistics Canada, 2003: Cattle and Calves on Farms, Semi-annually, by province, east, west and Canada, 2000 and 2001; 2001 and 2002.

vided was used to estimate gross energy (GE) required for both beef (NRC 1996) and dairy cattle (NRC 2001). Although not used in the calculation to estimate enteric emissions, feed intake was checked and compared with the weight of the animal in each subcategory by dividing the GE for each category by a default energy density of 18.45 MJ kg^{-1}, as suggested by (IPCC 2000). Based on the reported management practices (animal type, weight gain physiological state (lactating vs. pregnant), age, gender, production/feeding environment (confinement vs. pasture)), for dairy and beef cattle, distinct categories for each province were created. The number of categories differed for each province as management practices differed from province to province. Three to seven distinct subcategories were generated for dairy cattle (e.g., Ontario, Table 2) and 16 to 29 distinct subcategories were generated for beef cattle (e.g., Manitoba, Table 3).

Provincial and National Emission Estimates

Enteric CH_4 emissions were calculated using IPCC Tier-2 equations (IPCC 2000). In doing so, several assumptions were made: (a) Methane conversion rates, Y_m, percent of gross energy intake (%GEI) applied to enteric CH_4 emission estimates were 4 ± 0.005% for feedlot cattle, 6 ± 0.005% for dairy cows and 6 ± 0.005% for all other cattle (IPCC 2000); (b) methane emissions were converted to CO_2 eq. by multiplying annual emissions by 21 (Desjardins et al. 2001); (c) enteric CH_4 emissions were zero for calves less than 2–3 mo, as it has been demonstrated that at 90 d of age, calves on high milk intake consume less than 1000 g d^{-1} of herbage organic matter (Le Du et al. 1976); d) replacement heifers over 15 mo of age were assumed to be bred; (e) all replacement stock (young breeding bulls, and replacement heifers over 12 mo of age) were assumed to enter the breeding herd after 24 mo of age (Boadi et al. 2004a).

The amount of methane produced, also known as the emission factor (EF), was calculated using the Tier-2 equations and expressed as kg $head^{-1}$ yr^{-1}. For most categories, the time that cattle are in a given production environment is less than a year. Therefore, differences in cattle management over the course of the year were accounted for by summing the calculated emission factors from different production environments (i.e., cows in confinement and on pasture) or by extrapolating the calculated emission factors to 12 mo and then averaging the calculated emission factor (i.e., heifers finished directly after weaning and heifers backgrounded prior to finishing). As such, one emission factor was obtained for each category of cattle in each province. National emission factors for beef and dairy were then calculated by weighting provincial emission factors on the basis of provincial contribution to the national animal inventory.

Comparison of Methodologies

The computed enteric emission factors generated by IPCC Tier-2 methodology were compared with emission factors generated by IPCC Tier-1 and CRS conducted in production environments reflective of that utilized by the cattle industry. The IPCC Tier-1 emission factors (kg CH_4 $head^{-1}$ yr^{-1}) used were: 56 for dairy heifers; 118 for dairy cows; 75 for bulls; 72 for beef cows; 56 for beef heifers; 47 for calves; 47 for steers; and 47 for heifers for slaughter (IPCC 1997; Olsen et al. 2003). Emission factors generated from CRS were based on the following studies: (1) Boadi and Wittenberg (2002) in which yearling dairy heifers with an initial weight of 310 kg produced 258 L CH_4 d^{-1} or 6.7% GEI; (2) Kinsman et al. (1995) in which lactating dairy cows with an initial weight of 602 kg produced 552 L CH_4 d^{-1} or 8.9% GEI; (3) Boadi and Wittenberg (2002) in which beef heifers with an initial weight of 310 kg (confined, restricted intake of grass-legume hay) produced 195.8 L CH_4 d^{-1}or 6.9% GEI ; (4) Boadi and Wittenberg (2002) and Ominski et al. (2006) in which beef yearling heifers with an initial weight of 310 kg (confined, ad-libitum feeding) produced 258.7 L CH_4 d^{-1} and beef yearling steers with an initial weight of 262 kg (confined ad-libitum feeding) produced 193.3 L CH_4 d^{-1}, respectively, with an average methane loss of 6.0% GEI; (6) McCaughey et al. (1999) in which first calf cows with an initial body weight of 511.2 kg, grazing grass pastures produced 411.0 L CH_4 d^{-1} or 9.5% GEI; (7) Ominski et al. (2006) in which 343 kg beef yearling steers grazing grass-based pastures produced 198 L CH_4 d^{-1} or 8.7% GEI, and (8) Boadi et al. (2004b) in which feedlot steers with an initial body weight of 252 kg fed a diet con-

Table 2. Dairy cattle enteric methane estimates for Ontario in 2001 using IPCC Tier-2 methodology (Boadi et al 2004a)

Categories	Location	Time (d)	Avg. wt (kg)	No. of animals	ADG (kg d^{-1})	Diet DE (%)	DMI[z] (kg d^{-1})	GE (MJ d^{-1})	Y_m[x]	Annual EF[w] (kg $head^{-1}$ yr^{-1})	Methane (t yr^{-1})	EF[w] (kg $head^{-1}$)
Heifers	Confined	243.0	499.0	198 500	0.75	62.6	10.58	195.29	0.06	77	10 156	51
	Pasture	122.0	499.0	148 875	0.75	67.7	9.25	170.71	0.06	67	3 343	23
	Confined	122.0	499.0	49 625	0.75	62.6	10.58	195.29	0.06	77	1 275	26
Cows												
Lactating	Confined	303.3[y]	657.6	366 000	0.35	71.2	19.48	359.42	0.06	141	43 019	118
Dry	Pasture	20.6[y]	657.6	366 000	0.35	67.7	9.86	181.98	0.06	72	1 477	4
Dry	Confined	41.1[y]	657.6	366 000	0.35	63.4	9.73	179.56	0.06	71	2 914	8

[z]Daily dry matter intake calculated by IPCC Tier-2 equation (IPCC 2000).
[y]Actual time in production phase converted to 365-d basis.
[x]Y_m = methane conversion rate.
[w]EF = emission factor.

taining 84% barley grain and 11.5% barley silage, produced 127.9 L CH_4 d^{-1} or 2.5% GEI. The Y_m values (% GEI), reported in these studies were substituted for the Y_m values recommended by IPCC (IPCC 2000) for Tier-2 calculations. For some classes of cattle (i.e., bulls), CRS have not been conducted, and therefore the most appropriate Y_m values reported in the literature were used. As described above, for most categories, the time that cattle are in a given production is less than a year. Therefore, differences in cattle management over the course of the year were accounted for by summing the calculated emission factors from different production environments (i.e., cows in confinement and on pasture) or by extrapolating the calculated emission factors to 12 mo and then averaging the calculated emission factor (i.e., heifers finished directly after weaning and heifers backgrounded prior to finishing). As such, one emission factor was obtained for each category of cattle in each province. National emission factors were calculated for beef and dairy as described for Tier-2 methodology whereby provincial emission factors were weighted on the basis of provincial contribution to the national animal inventory.

Comparisons between emission factors generated by Tier-1 methodology, Tier-2 methodology and CRS were compared and expressed as a percent difference.

RESULTS AND DISCUSSION

Dairy Enteric Methane Emissions

Methane emissions from the dairy population in Canada (2001) as calculated by the IPCC Tier-2 methodology was 173 030 t yr^{-1} or 3.6 Mt CO_2 eq. for 2001 (Table 4). Emissions ranged from 708 t yr^{-1} in NF to 62,184 t yr^{-1} in Ontario. The range in emission estimates is largely influenced by differences in management practices utilized, time spent at each stage of production and population numbers in each province. Emission factors (kg CH_4 $head^{-1}$ yr^{-1}) for dairy heifers ranged from 70 in Quebec to 93 in Newfoundland, with a national emission factor of 73. Heifers in the latter province were raised on pasture for a period of time and had lower initial body weights leading to increased energy requirements for growth and pasture activity. The emission factor of dairy heifers in Alberta was 71 kg CH_4 $head^{-1}$ yr^{-1}, which is comparable with the emission factor of 72 kg CH_4 $head^{-1}$ yr^{-1} generated by Alberta Agriculture GHG assessment emission inventory using IPCC Tier-2 methodology [Alberta Agriculture, Food and Rural Development (AARFD) 2003].

A national emission factor of 126 kg CH_4 $head^{-1}$ yr^{-1} was generated for dairy cows with a range of 119 in QC to 144 kg CH_4 $head^{-1}$ yr^{-1} in BC (Table 4). Provinces in which most dairy cows were confined on a year-round basis (AB, SK, MB and BC) had emission factors similar to those provinces in which cows were confined in winter and pastured in summer (NF, PEI, ON and NB). Lowest emission factors for dairy cows were observed in QC and NS. Although dairy cows in these provinces were confined all year round, they tended to have lighter body weights, lower average daily gains and slightly lower milk production compared with cows in Western Canada, thus requiring lower net energy for maintenance, growth and lactation (Boadi et al. 2004a).

Beef Enteric Methane Emissions

Methane emissions from the Canadian beef herd as calculated using the IPCC Tier-2 methodology was 763 852 t yr^{-1} or 16.0 Mt CO_2 eq. for 2001 (Table 5). A range of 191 t yr^{-1} in NF to 356 345 t yr^{-1} in AB was observed. As with emission factors from dairy cattle, this range in values is attributed to reported differences in animal management and population. Emission factors (kg CH_4 $head^{-1}$ yr^{-1}) for beef cows ranged from 77 in Saskatchewan to 105 in Ontario, with a national average of 90. Although production practices were similar in Saskatchewan and Manitoba, emission factors in Saskatchewan deviated by –15.1% from the national average as a consequence of the reported lower body weights of cows from Ssakatchewan compared with those in Manitoba. The national emission factor for mature bulls (93 kg CH_4 $head^{-1}$ yr^{-1}) was similar to that of cows (90 kg CH_4 $head^{-1}$ yr^{-1}), reflecting similarities in genetics and production environment. A narrow range of 33–43 kg CH_4 $head^{-1}$ yr^{-1} was observed for calves < 1yr using the IPCC Tier-2 system, as calves less than 6 mo in all provinces were reported to be on pasture until weaning, with no consideration of creep feeding. This range is comparable with those determined for Alberta beef calves < 1yr using IPCC Tier-2 methodology (AARFD 2003).

Table 3. Beef cattle enteric methane estimates for Manitoba in 2001 using IPCC Tier-2 methodology (Boadi et al 2004a)

Categories	Age (mo)	Location	Time of year	Duration (mo)	Avg. wt (kg)	No. of animals	ADG (kg d^{-1})	Diet DE (%)	DMI[z] (kg d^{-1})	GE (MJ d^{-1})	Y_m[y]	Annual EF[x] (kg $head^{-1}$ yr^{-1})	Methane (t yr^{-1})	EF[x] (kg $head^{-1}$)
Beef cows – pregnant		Confined	Jan.-May/Nov.-Dec.	7.0	671.2	328 200	0.23	60.7	9.98	184.15	0.06	73	13 874	42
Beef cows – lactating		Pasture	Jun.-Oct.	5.0	671.2	328 200	0.23	65.0	14.79	272.90	0.06	107	14 686	45
Beef cows – pregnant		Confined	Feb.-Mar.	1.3	671.2	218 800	0.23	60.7	9.98	184.15	0.06	73	1 718	8
Beef cows – lactating		Pasture	Jan./Mar.-Dec.	10.7	671.2	218 800	0.23	65.0	14.79	272.90	0.06	107	20 953	96
Breeding bulls, mature		Confined	Jan.-Apr./Dec.	5.5	1088.4	19 500	0.00	61.4	10.76	198.54	0.06	78	698	36
Breeding bulls, mature		Pasture	May-Nov.	6.5	1088.4	19 500	0.00	65.0	11.59	213.75	0.06	84	889	46
Breeding bulls, young	13 to 16	Confined	Feb.-May	4.0	629.1	6 500	1.28	61.4	12.26	226.23	0.06	89	193	30
Breeding bulls, young	17 to 22	Pasture	Jun.-Nov.	6.0	824.3	6 500	1.28	65.0	14.93	275.50	0.06	108	352	54
Breeding bulls, young	23 to 24	Confined	Dec./Jan.	2.0	980.4	6 500	1.28	61.4	17.10	315.55	0.06	124	135	21
Beef calves, birth to pasture	0 to 2.5	Confined	Mar.-May	2.5	80.8	488 000	0.93	0.0	0.00	0.00	0.06	0	0	0
Beef calves, pasture	2.5 to 7.5	Pasture	Jun.-Oct.	5.0	187.8	488 000	0.93	65.0	5.22	96.25	0.06	38	7 702	16
Beef calves, heifer replacement	7.5 to 12	Confined	Nov.-Dec./Jan.-Mar.	4.5	306.0	86 943	0.68	62.4	6.86	126.49	0.06	50	1 623	19
Beef calves, background heifers	7.5 to 12	Confined	Nov.-Dec./Jan.-Mar.	4.5	332.0	44 921	1.06	68.8	7.69	141.96	0.06	56	941	21
Beef calves, background steers	7.5 to 12	Confined	Nov.-Dec./Jan.-Mar.	4.5	332.0	75 396	1.06	68.8	7.09	130.76	0.06	52	1 455	19
Beef calves, finisher heifers	7.5 to 12	Confined	Nov.-Dec./Jan.-Mar.	4.5	356.1	104 816	1.41	79.6	7.66	141.27	0.04	37	1 457	14
Beef calves, finisher steers	7.5 to 12	Confined	Nov.-Dec./Jan.-Mar.	4.5	356.1	175 924	1.41	79.6	6.98	128.80	0.04	34	2 229	13
Heifer replacement	13 to 15	Confined	Mar.-May	3.0	383.7	78 500	0.68	62.4	8.12	149.89	0.06	59	1 158	15
Heifer replacement	16 to 20	Pasture	Jun.-Oct.	5.0	466.7	78 500	0.68	65.0	10.15	187.22	0.06	74	2 410	31
Heifer replacement	21 to 24	Confined	Nov.-Dec./Jan.-Feb.	4.0	560.0	78 500	0.68	62.4	11.39	210.20	0.06	83	2 165	28
Finisher heifers	13 to 15	Confined	Mar.-May	3.0	517.3	38 150	1.41	79.6	10.13	186.93	0.04	49	468	12
Finisher steers	13 to 15	Confined	Mar.-May	3.0	517.3	55 650	1.41	79.6	9.24	170.43	0.04	45	622	11
Finisher heifers- backgrounded	13 to 17	Confined	Mar.-Jul.	5.0	512.3	11 854	1.41	79.6	10.06	185.57	0.04	49	241	20
Finisher steers – backgrounded	13 to 17	Confined	Mar.-Jul.	5.0	512.3	17 291	1.41	79.6	9.17	169.19	0.04	44	320	19
Background heifers	13 to 15	Confined	Mar.-May	3.0	453.3	4 496	1.06	68.8	9.72	179.31	0.06	71	79	18
Background steers	13 to 15	Confined	Mar.-May	3.0	453.3	6 559	1.06	68.8	8.95	165.16	0.06	65	107	16
Background heifers	16 to 18	Pasture	Jun.-Aug.	3.0	550.3	4 496	1.06	65.0	13.41	247.43	0.06	97	110	24
Background steers	16 to 18	Pasture	Jun.-Aug.	3.0	550.3	6 559	1.06	65.0	12.41	229.05	0.06	90	148	23
Finisher heifers	19	Confined	Sep.	0.5	609.5	4 496	1.41	79.6	11.46	211.40	0.04	56	10	2
Finisher steers	19	Confined	Sep.	0.5	609.5	6 559	1.41	79.6	10.45	192.74	0.04	51	14	2

[z]Daily dry matter intake calculated by IPCC Tier-2 equation (IPCC 2000).
[y]Y_m = methane conversion rate.
[x]EF = emission factor.

Table 4. Summary of dairy cattle enteric methane emissions by province in 2001 using IPCC Tier-2 methodology

	Heifers		Cows		Total	
Province	Annual EF[z] (kg head^{-1} yr^{-1})	Methane (t yr^{-1})	Annual EF[z] (kg head^{-1} yr^{-1})	Methane (t yr^{-1})	Methane (t yr^{-1})	CO_2 -Equivalent[y] (t yr^{-1})
BC	72	2 516	144	10 644	13 160	276 357
AB	71	2 645	127	11 609	14 254	299 335
SK	75	1 032	127	3 693	4 726	99 237
MB	72	1 378	134	5 664	7 042	147 881
ON	75	14 734	130	47 410	62 184	1 305 859
QC	70	12 441	119	49 181	61 621	1 294 050
NF	93	135	122	573	708	14 861
NB	77	733	131	2 507	3 239	68 026
NS	78	895	119	2 854	3 749	78 722
PEI	75	521	125	1 827	2 348	49 312
All Provinces	73[x]	37 070	126[x]	135 960	173 030	3 633 638

[z]EF = emission factor.
[y]CO_2 -equivalent (t yr^{-1}) = methane emissions (t yr^{-1}) × 21.
[x]Weighted average (based on provincial inventory contribution to national population).

Emission factors for replacement heifers in Ontario (90 kg CH_4 head^{-1} yr^{-1}) and Quebec (97 kg CH_4 head^{-1} yr^{-1}) were higher than that observed in other provinces as a consequence of the reported higher body weights. A national emission factor of 75 kg CH_4 head^{-1} yr^{-1} which was calculated in this study is comparable with that generated (73 kg CH_4 head^{-1} yr^{-1}) in the United States for beef heifers, 12–23 mo of age, using the same IPCC Tier-2 methodology (Inventory of US Greenhouse Gas Emissions and Sinks 1990–2000 (Annex K) 2001). Emission factors for heifers > 1 yr and steers > 1 yr were dependent on the production system (feedlot vs. backgrounding) and the duration of time spent in either production system. As expected, emission factors for provinces (Quebec, New Brunswick and Prince Edward Island) in which heifers > 1 yr and steers > 1 yr were sent directly to feedlot were lower compared with those having all animals backgrounded (Newfoundland), or provinces using both production systems (British Columbia, Alberta, Saskatchewan, Manitoba, Ontaio, Nova Scotia). National emission factors of 63 and 56 kg CH_4 head^{-1} yr^{-1} were generated for heifers > 1 yr and steers > 1 yr, respectively (Table 5).

Uncertainties Associated with Tier-2 Methodology

Use of Tier-2 methodology requires a detailed characterization of the cattle population. As identified by IPCC (2000), each item of information used in the characterization has associated uncertainty, the level of which depends on the method of collection. As such, uncertainties in the Tier-2 estimates presented here may be associated with population data, production practices and performance data, including feeding strategy.

The two key uncertainties related to population data are associated with data collection and reporting. Population data reported by national agencies are obtained by telephone or written survey and, as such, are subject to interpretation by the respondent. In addition, several categories of animals may be reported as a single value, for example, calves and bulls are not reported separately for dairy and beef cattle making it difficult to characterize these populations. Further, the management strategies associated with beef and dairy calves differ, leading to an underestimate of feed quality and intake.

Uncertainties also exist in the characterization of cattle management and performance as published survey data are limited. To overcome this problem, much of this information was obtained from survey data collected from provincial and regional livestock specialists. Due to the large area and different climatic zones in which cattle are reared in Canada, production practices in the livestock sector are highly variable from farm-to-farm and region-to-region. Furthermore, they can vary from month-to-month and year-to-year, as dictated by economic viability and weather. The production practices reported by these individuals are those which are most commonly utilized and do not include novel management strategies employed by a portion of the industry. Included in this is uncertainty associated with feed/pasture quality, which was estimated for several provinces, and the use of alternative feeding strategies (including ionophores), which are not accounted for in the Tier-2 methodology. Finally, the enteric emissions calculated in this report do not account for cold acclimation experienced by beef cattle during the winter period in much of the Canadian production environment. Cold acclimation leads to increased rate of feed passage (Kennedy and Milligan 1978). As it has been demonstrated that increased rate of passage leads to a reduction in enteric emissions (Okine et al. 1989), it is anticipated that enteric emissions would be reduced under these circumstances.

Comparison of National Emission Factors

A comparison of national emission factors using IPCC Tier-1, IPCC Tier-2 and CRS is given in Table 6. In general, IPCC Tier-1 estimates for enteric methane emissions were lower than those generated using IPCC Tier-2 methodology. For example, emission factors for dairy and beef cows using IPCC Tier-2 were 6.4 and 20.3% higher than IPCC Tier-1, respectively. This trend can be expected as IPCC Tier-1 does not account for differences in performance and feeding practices (IPCC 2000). On the contrary, IPCC Tier-1 estimates were 15.1% higher for calves < 1yr when compared with IPCC Tier-2 methodology. Use of the IPCC Tier-1 methodology yields an emission factor of 47 CH_4 kg head^{-1} yr^{-1} for calves while the value generated using Tier-2 methodology is 40 kg head^{-1} yr^{-1}. This difference may be accounted for by the changes in the production environment associated with the latter methodology. As it has been demonstrated that at 90 d of age, calves consume less than 1000 g d^{-1} of herbage organic matter (Le Du et al. 1976), it was assumed that calves < 3 mo produced negligible amounts of CH_4. Similarly, the US national inventory assumed no emissions for calves < 6 mo (Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2000 (Annex K) 2001).

A comparison of emission factors generated using IPCC Tier-2 and those observed in CRS (Table 6) demonstrated that emission factors generated by the latter were 12.3% lower to 32.6% higher than those generated by Tier-2 methodology. The Tier-2 methodology uses a standardized methane conversion rate or Y_m (IPCC 2000) of 6% GEI for all classes for cattle, except those in the feedlot for which a Y_m of 4% GEI is used. As observed in Table 7, Y_m based on CRS were equal or higher than the default values provided by IPCC (2000), with the exception of animals in the feedlot (Boadi et al. 2004b). Thus, Y_m values suggested by IPCC (2000) were lower for all dairy cattle and for mature classes of beef cattle (cows and bulls), as well as growing animals on pasture compared with Y_m obtained from CRS. Conversely, IPCC (2000) Y_m values were higher for animals in a feedlot environment. Values obtained from CRS for younger animals fed forage-based rations in confinement were comparable to those suggested by IPCC (2000).

As the agricultural landscape in Canada includes some 4 804 496 ha of tame or seeded pasture and 15 391 072 ha of natural land for pasture (`Statistics Canada, 2001), a significant portion of cattle are grazing grass-based pastures. As such, only those Canadian research studies conducted on low fertility pastures were used (McCaughey et al. 1999; Ominski et al. 2006) rather than studies which have been conducted on pastures containing significant quantities of legume (McCaughey et al. 1997).

The observed difference in Y_m recommended by IPCC (2000) compared with CRS for feedlot cattle (4.0 vs. 2.5%) may be attributed to the use of alternative feeding strategies. Inclusion of fats and ionophores in the diet, which were used in the CRS, may lead to a reduction in enteric CH_4 emissions (Mathison 1997; Boadi et al. 2004b, Beauchemin and McGinn 2006). Also, it has been demonstrated that source of grain (barley vs. corn) may influence enteric emissions (Beauchemin and McGinn 2005). At the present time, it would not be prudent to utilize the Y_m values obtained by CRS for feedlot cattle for several reasons. Although fat supplementation has been demonstrated to reduce enteric methane emissions, its use is dictated by cost and, therefore, is not used consistently across the country. Further, Guan et al. (2006) have demonstrated that reductions in enteric emissions associated with the use of feed additives, such as ionophores, may not be sustained with long-term feeding. Research conducted at the Agriculture and Agri-Food Canada Station in Lethbridge has demonstrated that addi-

Table 5. Summary of beef cattle enteric methane emissions by province in 2001 using IPCC Tier- 2 methodology

	Cows		Bulls		Calves < 1 yr		Replacement heifers		Heifers >1 yr		Steers >1 yr		Total	
Prov.	Annual EF[z] (kg head^{-1} yr^{-1})	Methane (t yr^{-1})	Annual EF[z] (kg head^{-1} yr^{-1})	Methane (t yr^{-1})	Annual EF[z] (kg head^{-1} yr^{-1})	Methane (t yr^{-1})	Annual EF[z] (kg head^{-1} yr^{-1})	Methane (t yr^{-1})	Annual EF[z] (kg head^{-1} yr^{-1})	Methane (t yr^{-1})	Annual EF[z] (kg head^{-1} yr^{-1})	Methane (t yr^{-1})	Methane (t yr^{-1})	CO_2 -equivalent[y] (t yr^{-1})
BC	95	26 967	106	1 649	37	8 314	82	4 162	64	401	59	891	42 384	890 059
AB	93	186 078	96	9 581	43	88 264	76	23 564	65	22 051	59	26 807	356 345	7 483 247
SK	77	94 356	87	4 986	37	37 279	61	11 814	55	661	50	1 145	150 240	3 155 042
MB	95	51 231	93	2 267	33	15 407	73	5 732	60	907	55	1 210	76 753	1 611 822
ON	105	39 672	90	2 020	40	26 010	90	7 097	60	3 419	55	5 263	83 482	1 753 111
QC	104	21 820	96	1 271	42	5 823	97	3 191	41	436	38	1 549	44 091	925 908
NF	85	55	105	11	45	90	68	20	99	5	91	10	191	4 020
NB	98	2 000	97	125	39	966	80	369	46	69	42	99	3 628	76 179
NS	90	2 352	84	119	41	1 201	68	349	70	46	64	68	4 134	86 809
PEI	88	1 181	88	73	33	635	71	219	48	186	44	312	2 605	54 695
All Prov.	90[x]	425 711	94[x]	22 101	40[x]	193 989	75[x]	56 ,517	63[x]	28 181	56[x]	37 353	763 852	16 040 892

[z]EF = emission factor.
[y]CO_2-equivalent (t yr^{-1}) = methane emissions (t yr^{-1}) × 21.
[x]Weighted average (based on provincial inventory contribution to national population).

Table 6. Comparison of national emission factors using IPCC Tier-1, IPCC Tier-2 methodology and Canadian research studies (CRS)

Categories	Tier-1 (kg CH_4 head^{-1} yr^{-1})	Tier-2 (kg CH_4 head^{-1} yr^{-1})	CRS[z] (kg CH_4 head^{-1} yr^{-1})	Tier-2 vs. Tier-1 (% difference)[x]	CRS vs. Tier-2 (% difference)[w]
Dairy					
Heifers	56	73	77	23.0	5.1
Cows	118	126	187[y]	6.4	32.6
Beef					
Cows	72	90	126	20.3	28.3
Bulls	75	94	121	19.8	22.6
Calves < 1yr	47	40	46	–15.1	13.4
Heifer Rep.	56	75	88	25.1	15.3
Heifers > 1yr	47	63	56	25.3	–12.3
Steers > 1yr	47	56	50	16.2	–12.2

[z]Estimated emission factors based on Y_m values generated from CRS.
[y]Study included only lactating and close up cows.
[x]% difference = (Tier2 –Tier1)/Tier 2 × 100.
[w]% difference = (CRS –Tier2)/CRS × 100.

Table 7. Comparison of methane conversion rates (Y_m) recommended by IPCC Tier-2 (2000) and those obtained from Canadian research studies (CRS)

Categories	IPCC Y_m (% GEI)	CRS Y_m (% GEI)
Dairy heifers	6	6.7[z]
Dairy cows	6	8.9[y]
Beef cows (confined)	6	6.9[x]
Beef cows (pasture)	6	9.5[w]
Mature bulls (confined)	6	6.9[x]
Mature bulls (pasture)	6	9.5[w]
Immature bulls (confined)	6	6.0[v]
Immature bulls (pasture)	6	8.7[u]
Calves < 1 yr (confined)	6	6.0[v]
Calves < 1 yr (pasture)	6	8.7[u]
Calves < 1 yr (feedlot)	4	2.5[t]
Replacement heifers (confined)	6	6.0[v]
Replacement heifers (pasture)	6	8.7[u]
Heifers >1 yr (confined)	6	6.0[v]
Heifers > 1 yr (pasture)	6	8.7[u]
Heifers > 1 yr (feedlot)	4	2.5[t]
Steers > 1 yr (confined)	6	6.0[v]
Steers > 1 yr (pasture)	6	8.7[u]
Steers > 1 yr (feedlot)	4	2.5[t]

[z]Based on 310-kg dairy yearling heifers producing 258 L CH_4 d^{-1} (Boadi and Wittenberg 2002).
[y]Based on 602-kg lactating cows producing 552 L CH_4 d^{-1} (Kinsman et al. 1995).
[x]Based on 310-kg beef heifers under confined feeding (at restricted intake of grass legume hay) producing 195.8 L CH_4 d^{-1} (Boadi and Wittenberg 2002).
[w]Based on 511-kg first calf cows grazing grass pasture 411 L CH_4 d^{-1} (McCaughey et al. 1999).
[v]Based on 310-kg beef yearling heifers (confined ad-libitum feeding) producing 258.7 L CH_4 d^{-1} (Boadi and Wittenberg 2002) and 262 kg beef yearling steers (confined ad-libitum feeding) producing 193.3 L CH_4 d^{-1} (Ominski et al. 2006).
[u]Based on 343-kg beef yearling steers grazing grass-based pastures producing 198 L CH_4 d^{-1} (Ominski et al. 2006).
[t]Based on 252-kg feedlot steers (84% barley grain + 11.5 % barley silage) diet producing 127.9 L CH_4 d^{-1} (Boadi et al. 2004b).

tives such as fumaric acid and yeast (McGinn et al. 2004), as well as an essential oil and spice extract (Beauchemin and McGinn 2006) did not affect enteric CH_4 emissions when expressed as a %GEI. Finally, feedlot trials conducted during the winter months may yield lower Y_m values as a consequence of the relationship between cold acclimation and rate of passage (Kennedy and Mulligan 1978), as well as rate of passage and reduced enteric emissions (Okine et al. 1989) described above. Additional research is required to ascertain Y_m values for feedlot cattle reared in the Canadian production environment.

CONCLUSIONS

The study has shown that Canadian estimates of enteric CH_4 emissions differ when calculated using the IPCC Tier-2 methodology compared with the IPCC Tier-1 methodology currently used. Although Tier-2 methodology requires considerably more production and management information, uncertainties are still associated with this methodology and have been described herein. Accuracy of these emission estimates may be improved with a more complete characterization of the management strategies and population data for all classes of cattle throughout the production cycle. Further, there are still gaps in the CRS for several classes of cattle including beef cows in confinement, bulls in confinement and on pasture, lactating and dry dairy cattle, suckling calves on pasture and long-term feedlot trials. The Y_m values obtained from studies conducted in these production environments could be utilized in the Tier-2 equations, along with the Y_m values that have already been published for several other production scenarios, to generate emission estimates for the Canadian cattle herd.

ACKNOWLEDGEMENTS

This study was supported by funding from Environmental Canada. The authors would like to extend sincere thanks to the provincial and regional specialists who provided the valuable information garnered from the survey. Further, the input and advice of greenhouse gas scientists from across Canada and the United States was paramount to the successful completion of this endeavor.

Alberta Agriculture, Food and Rural Development. 2003. Development of farm-level greenhouse gas assessment: Identification of knowledge gaps and development of a science plan. AARI Project Number 2001J204. pp. 2–16.

Basarab, J. A., Okine, E. K., Baron, V. S., Marx, T., Ramsey,

P., Ziegler, K. and Lyle, K. 2005. Methane emissions from enteric fermentation in Alberta's beef cattle population. Can. J. Anim. Sci. **85**: 501–512.

Beauchemin, K. and McGinn, S. M. 2006. Methane emissions from beef cattle: Effects of fumaric acid, essential oil, and canola oil. J. Anim. Sci. **84**: 1489–1496.

Beauchemin, K. and McGinn, S. M. 2005. Methane emissions from feedlot cattle fed barley or corn diets. J. Anim. Sci. **83**: 653–661.

Boadi, D. A. and Wittenberg, K. M. 2002. Methane production from dairy and beef heifers fed forages differing in nutrient density using the sulfur hexafluoride (SF_6) tracer gas technique. Can. J. Anim. Sci. **82**: 151–157.

Boadi, D. A., Ominski, K. H., Wittenberg, K. M. and Fulawka, D. L. 2004a. Improving estimates of methane emissions associated with enteric fermentation of cattle in Canada by adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology. Solicitation number: K2362-3-0088. Final report submitted to Environment Canada, 2004 Oct. 20.

Boadi, D. A., Wittenberg, K. M., Scott, S. L., Burton, D., Buckley, K., Small, J. A. and Ominski, K. H. 2004b. Effect of low and high forage diet on enteric and manure pack greenhouse gas emissions from a feedlot. Can. J. Anim. Sci. **84**: 445–453.

Desjardins, R. L., Kulshreshtha, S. N., Junkins, B., Smith, W., Grant, B. and Boehm, M. 2001. Canadian greenhouse gas mitigation options in agriculture. Nutrient Cycling Agroecosyst. **60**: 317- 326.

Guan, H. T., Wittenberg, K. M., Ominski, K. H. and Krause, D. O. 2006. Efficacy of ionophores in cattle diets for mitigation of enteric methane. J. Anim. Sci. **84**:1896–1906.

International Panel on Climate Change. 1997. Greenhouse gas reference manual. Vol. 3. Revised 1996 IPCC guidelines for national greenhouse gas inventories. Intergovernmental Panel on Climate Change, Bracknell, UK.

International Panel on Climate Change. 2000. Good practice guidance and uncertainty management in national greenhouse gas inventories accepted IPCC Plenary in Montreal, 1–8 May 2000, Vol. 3. J. T. Houghton, L.G. Meira Filho, B. Lim, K. Treanton, I. Mamaty, Y. Bonduki, D. J. Griggs, and B. A. Callanders, eds. OECD/OCDE, Paris, France.

Janzen, H. H., Desjardins, R. L., Asselin, J. M. R. and Grace, B. 1998. The health of our air: Towards sustainable agriculture in Canada. Research Branch, Agriculture and Agri-Food Canada, Ottawa, ON. Publ. no. A53–1981/1998E.

Kennedy, P. M. and Milligan, L. P. 1978. Effects of cold exposure on digestion, microbial synthesis and nitrogen transformation in sheep. Br. J. Nutr. **39**: 105–117

Kinsman, R., Sauer, F. D., Jackson, H. A. and Wolynetz, M. S. 1995. Methane and carbon dioxide emissions from dairy cows in full lactation monitored over a six-month period. J. Dairy Sci. **78**: 2760–2766.

Le Du, Y. L. P., Baker, R. D. and Barker, J. M. 1976. Milk-fed calves. 2. The effect of length of milk feeding period and milk intake upon herbage intake and performance of grazing calves. J. Agric. Sci. (Camb.) **87**: 197–204.

Mathison, G.W. 1997. Effect of canola oil on methane production in steers. Can. J. Anim. Sci. **77**: 545–546 (Abstr.).

McCaughey, W. P., Wittenberg, K. and Corrigan, D. 1999. Impact of pasture type on methane production by lactating beef cows. Can. J. Anim. Sci. **79**: 221–226.

McCaughey, W. P., Wittenberg, K. and Corrigan, D. 1997. Methane production by steers on pasture. Can. J. Anim. Sci. **77**: 519–524.

McGinn, S. M., Beauchemin, K. A., Coates, T. and Colombatto, D. 2004. Methane emissions from beef cattle: Effects of monensin, sunflower oil, enzymes, yeast and fumaric acid. J. Anim. Sci. **82**: 3346–3356.

National Research Council. 2001. Nutrient requirements of dairy cattle. 7th rev. ed. National Academy Press, Washington, DC.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC.

Olsen, K., Wellisch, M., Boileau, P., Blain, D., Ha, C., Henderson, L., Liang, C., McCarthy, J. and McKibbon, S. 2003. Canada's greenhouse gas inventory, 1990–2001. Greenhouse Gas Division, Environmental Canada. Ottawa, ON. August 2003.

Okine, E. K., Mathison, G. W. and Hardin, R. T. 1989. Effects of changes in frequency of reticular contractions on fluid and particulate passage rates in cattle. J. Anim. Sci. **67**: 3388–3396.

Ominski, K. H., Boadi, D. A. and Wittenberg, K. M., 2006. Enteric methane emissions from backgrounded cattle consuming all-forage diets. Can. J. Anim. Sci. **86**: 393–400.

Ontario Dairy Herd Improvement Services. 2003. 2003 Progress Report. Guelph, ON.

Statistics Canada 2003. Livestock statistics Fourth Quarter 2002. Statistics Canada, Agriculture Division, Livestock and Animal Products Section. March 2003. Catalogue no. 20–603-XIE, ISSN 1703–1478.

Statistics Canada. 2001. Table 5.1, Land use, by province, Census Agricultural Region (CAR) and Census Division (CD), Catalogue No. 95F0301XIE.

United States Environmental Protection Agency. 2001. Inventory of U.S Greenhouse Gas Emissions and Sinks 1990–2000, EPA-430-R-01-001 (Washington DC, April 2001).

Western Canadian Dairy Herd Improvement Services. 2002. 2002 Herd Improvement Report. Edmonton, AB.