Assessment of Greenhouse Gas Emissions from Poultry Enteric Fermentation

Shu-Yin Wang* and Da-Ji Huang[1]

Department of Animal Science, Chinese Culture University, 55 Hwa Kang Rd, Taipei, Taiwan, ROC

ABSTRACT : Emissions of nitrous oxide (N_2O) and methane (CH_4) from poultry enteric fermentation were investigated using a respiration chamber. Birds were placed in a respiration chamber for certain intervals during their growing period or for the whole life cycle. The accumulated gas inside the chamber was sampled and analyzed for N_2O and CH_4 production. A curve for gas production during a life cycle was fitted. The calculated area under the curve estimated the emission factor of poultry enteric fermentation on a life cycle basis (mg bird^{-1} life cycle^{-1}). This method can be used to estimate CH_4 or N_2O emissions from different types of avian species taking into account factors such as diet, season or thermal effects. The CH_4/N_2O emission factors estimated for commercial broiler chickens, Taiwan country chickens and White Roman Geese were 15.87/0.03, 84.8/16.4 and 1,500/49 (mg bird^{-1} life cycle^{-1}), respectively, while the calculated CH_4/N_2O emission from enteric fermentations were 3.03/0.006, 14.73/2.84 and 9.5/0.31 (Mg year^{-1}), respectively in Taiwan in the year of 2000. The described method is applicable to most poultry species and the reported emission factors were applicable to meat type poultry only. ***(Asian-Aust. J. Anim. Sci. 2005. Vol 18, No. 6 : 873-878)***

Key Words : Nitrous Oxide, Methane, Respiration Chamber, Enteric Fermentation, Emission Factors

INTRODUCTION

The natural greenhouse effect is the result of heat absorption by certain gases (known as greenhouse gases (GHG Houghton, 1999)) in the atmosphere and re-radiation downward of some of the heat that helps to regulate the temperature of our planet. However, human activities have increased the concentration of greenhouse gases in the atmosphere (Houghton et al., 2001). Some GHG are emitted as a result of livestock production with animals directly contributing to emissions through enteric fermentation and manure management. Methane is produced during the normal digestive processes of animals. Ruminant animals are the major contributors to methane emission due to the type of digestive process by which carbohydrates are broken down by micro-organisms and methane is released as a by-product of enteric fermentation (Stevens and Hume, 1995). Non-ruminant animals also produce some methane, although not as much as ruminants due to the limitation of enteric fermentation occurrence in the post-gastric compartment such as ceccum and large intestines (Robinson et al., 1989; Sukahara and Ushida, 2000). To estimate methane emissions from enteric fermentation, the IPCC (Intergovernmental Panel on Climate Change) Guidelines recommended multiplying the number of animals for each animal category by an appropriate emission factor (IPCC, 1996). In the Reference Manual of the IPCC Guidelines, default emission factors for estimating methane emission from enteric fermentation are provided (Crutzen et al., 1986; Gibbs et al., 1993). However, an emission factor for poultry is absent on the list. The reason for non-inclusion emission factor is not clear, and may be due to unavailability of data or perceived insignificance of the data in the total inventory. In those countries where there are large poultry industries, the enteric fermentation emission factor for poultry is required to assess the total GHG inventory. The purpose of this study was to establish a method for the assessment of GHG emissions from poultry enteric fermentation. This method can be applied universally and can be used to predict both methane and nitrous oxide emissions.

MATERIALS AND METHODS

Unlike other livestock, life cycles of most poultry species are less than a year, and the growth rate changes dramatically during the life cycle. Therefore it is important not to use the average weight for estimates of emissions. In this study, the GHG production during the growing periods of broiler chicken (0-6 weeks), Taiwan country chicken (0-13 weeks) and White Roman geese (0-12 weeks) were estimated. The total emission for each of their life cycles was calculated until the day the animals were marketed or slaughtered. With this method the length of life cycle can be adapted to the local practice.

Animals

For the purpose of establishing the method, commercial broiler chickens (Arbor Acre), Taiwan country chickens and White Roman geese were randomly selected and raised from hatching to the end of the experiment (market weight). Four hundred broiler chickens, 200 Taiwan country

* Corresponding Author: Shu-Yin Wang. Tel: +886-2-28610511 (543), Fax: +886-2-28613100, E-mail: sywang@faculty.pccu.edu.tw

[1] Institute of Zoology, National Taiwan University, Taipei, Taiwan, ROC.

Received March 17, 2004; Accepted November 19, 2004

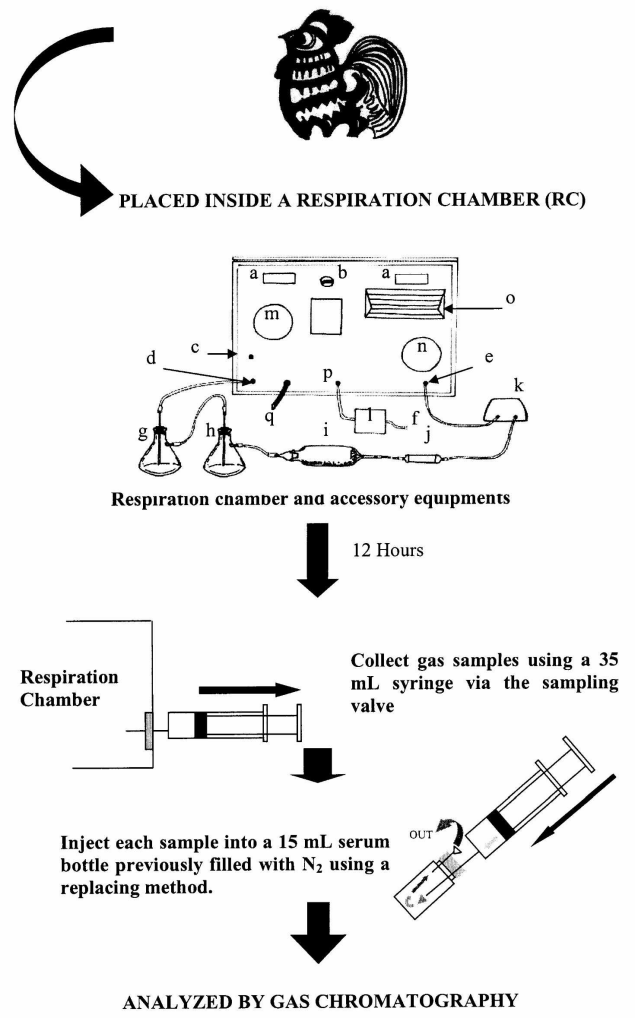

Figure 1. Respiration chamber used in the assessment of greenhouse gases. a: fan, b: light globe, c: sample outlet, d: circulation outlet, e: circulation inlet, f: connected to oxygen tank, g: water trap (with desiccant), h: flask containing KOH, i: water trap, j: filtration train, k: pump, l: timer and pressure valve, m: thermometer, n: hygrometer, o: radiator, p: oxygen inlet, q: power supply.

chickens and 20 White Roman geese were raised for 6, 13 and 12 weeks, respectively. The experiments were done separately. Broiler chickens and Taiwan country chickens were raised in the floor which is a common way of raising broiler chickens in Taiwan. Geese were raised in cages (90 cm×56 cm×60 cm, 4 birds/cage). During the experiment, all birds were fed commercial diets. The quality of the diets was provided by the feed suppliers. The feed consumption were recorded daily and the body weight were measured weekly and prior to each sampling trial. The Birds were placed in a respiration chamber for 12 h at weekly intervals in the case of Taiwan country chicken and White Roman geese, and twice a week in the case of broiler chicken, for a total of 12-13 times. The market live weight for broiler chickens, Taiwan country chickens and White Roman geese were 1.88 kg, 2.0 kg and 4.0 kg, respectively.

Respiration chamber

The respiration chamber was modified according to the design by Farrell (Farrell, 1972). Two different sizes were used. Chamber A (90×60×60 cm) was used for chickens (5-20 birds of body weight from 0.5 kg to 1.88 kg) and geese (2-10 birds of body weight from 0.2 kg to 4 kg) of up to a total weight of 10 kg. Chamber B (60×60×45 cm) was used for chickens of up to a total weight of 2.5 kg (5-20 chicks). The air was circulated with a pump; CO_2 and water vapor were absorbed in 10 N KOH and $CaCl_2$, respectively. The chamber was also equipped with an oxygen tank. Oxygen was supplemented when pressure fell below atmospheric pressure. Birds were put in a wire cage without litter materials on the floor to avoid CH_4 and N_2O emission induced by the addition of carbon source to the excreta.

Sampling

Gas samples were collected using a 35 ml syringe via the sample outlet at 0 and 12 h after placing the birds in the chamber. Samples were injected into a 15 ml serum bottle previously filled with N_2 using a displacement method. Reference gases had been used to flush the vial to verify the adequacy of flushing volume. Five samples were collected at each sampling time and stored at room temperature for CH_4 and N_2O analysis. The use of respiration chamber and the sampling procedure is summarized in Figure 1.

Greenhouse gas analysis

Methane was analyzed by Shimadzu 14B gas chromatography (Shimadzu, Japan) with flame ionization detector (FID) using Porapak Q (0.32 mm×2 m) column (Supelco, USA) and N_2 as carrier gas. The oven temperature, injection temperature and detector temperature were 70°C, 130°C and 130°C, respectively. The flow rate was set at 10 ml min^{-1}. Nitrous oxide was analyzed with electron capture detector (ECD) using Porapak Q (0.32 mm×3 m) column and P-10 (90% Ar+10% CH_4) as carrier gas. Two reference gases CH_4 (95%) and N_2O (100 ppm, ScottyII) were used for standard curve preparations. The concentrations used for calibration were 0.1, 0.5, 1, 5, 10, 50, 100, 500, 1,000 ppm and 10, 50, 100, 500, 1,000 ppb for CH_4 and N_2O, respectively. The standard curve for CH_4 is usually linear and the R^2, Coefficient of Variation (CV) and minimum detecting concentration were >0.998, <4.7% and 0.5 ppm, respectively. The average background air and 0 h chamber CH_4 concentrations were 1.841±0.547 ppm and 5.128± 0.501 ppm. The standard curve for N_2O is usually curvilinear, however in the range of 10 to 1,000 ppb, the curve is usually linear and the R^2, CV and minimum detecting concentration were >0.997, <6% and 10 ppb, respectively. The average background air and 0 h chamber

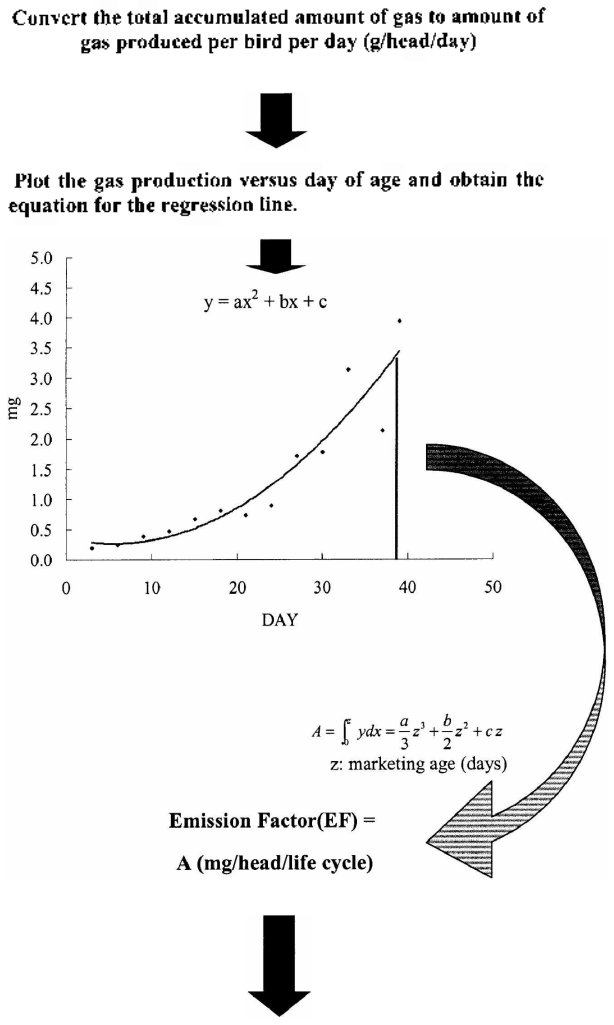

Figure 2. Conversion of greenhouse gas concentration to emission factor.

N_2O concentrations were 482.85±0.547 ppb and 607±258 ppb, respectively.

Emission factors

The accumulated GHG in 12 h in the chamber was obtained by subtracting 0 h concentration from 12 h concentration (ppm or ppb) and then converted to the amount of GHG (mg) produced in the chamber 12 h. The total gas was then converted into amount of gas produced by each bird per day (mg $head^{-1}$ day^{-1}). A plot of gas production versus day of age was produced. Regression curves were obtained and the areas under the curves were calculated. Although a hypothetical quadratic curve was set as a pre-model for the meat type poultry whose market age is 12 weeks from maturity. It should be recognized that the extrapolations might not be appropriate for meat type

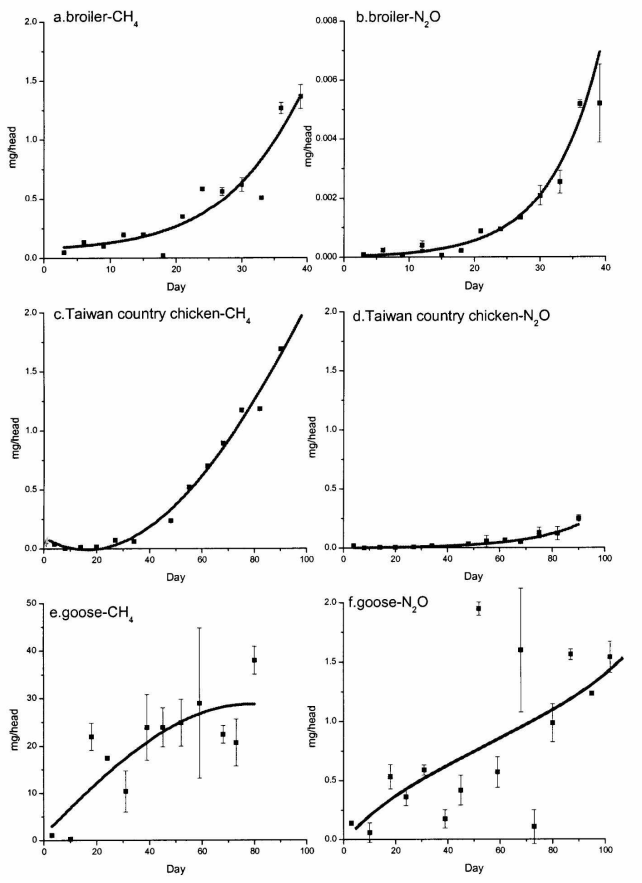

Figure 3. CH_4 and N_2O production from broilers, Taiwan country chickens and geese from hatch to market live weight. The temperature during the experimental period for broilers, Taiwan country chickens and geese were 19.43±2.82°C, 26.1±0.36°C and 21.1±2.4°C, respectively. a/b, c/d, e/f, methane/ nitrous oxide production from broilers, Taiwan country chickens and geese, respectively. The R^2 values for the regression lines ranged from 0.758 to 0.995.

poultry. The area under the curve represents the estimated total gas emission per bird per life cycle (mg $head^{-1}$ life $cycle^{-1}$) and can be used as an emission factor for each type of bird. Environmental temperature and feeding regime of the birds were taken into consideration (Figure 2). The length of the life cycle can be altered according to the subgroup of poultry species and the local practice. We used Origin 3.0 (Micro Cal, MA, USA) to process the regression and to calculate the area under the curve; however, these procedures can be followed using any software package or hand calculations.

RESULTS AND DISCUSSION

This method was used to estimate the emission factors for three species of birds kept at three different temperatures. A few examples of plots and the regression curves of CH_4 and N_2O emissions for the three tested avian species are shown in Figure 3. The R^2 values for the

Table 1. CH_4 and N_2O production from enteric fermentation of broiler chicken in Taiwan in 2000 (The annual production in the year of 2000 was 191,202,000 birds)

	Cold (<15°C)		Cool (15-25°C)		Warm (>25°C)		Average emission factor[a]	Total emission (t/year)
	Emission factor[a]	%[b]	Emission factor[a]	%[b]	Emission factor[a]	%[b]		
CH_4	20.44	23.3	16.26	51.7	10.79	25	15.87	3.034
N_2O	23		46		16.2		30	0.0057

[a] Emission factor for CH_4 and N_2O are mg head^{-1} life cycle^{-1} and μg head^{-1} life cycle^{-1}, respectively.
[b] Percentage of annual production (number of bird slaughtered).

Table 2. Emission factors of CH_4 and N_2O from enteric fermentation by different poultry species in Taiwan

Species	CH_4	N_2O
	(kg head^{-1} life cycle^{-1})	
Broilers	1.587×10^{-5}	3×10^{-8}
Taiwan country chickens	8.482×10^{-5}	1.635×10^{-5}
Geese	1.5×10^{-3}	4.90×10^{-5}

regression curves ranged from 0.758 to 0.995. Emission factors were obtained by calculating area under the curves. The calculated total emissions for broiler chickens in the year of 2000 for Taiwan (as an example) are summarized in Table 1.

Methane emission factors estimated for commercial broiler chickens, Taiwan country chickens and White Roman Geese were 15.87, 84.8 and 1,500 (mg head^{-1} life cycle^{-1}), respectively. Nitrous oxide emission factors estimated for commercial broiler chickens, Taiwan country chickens and White Roman Geese were 0.03, 16.4 and 49 (mg head^{-1} life cycle^{-1}), respectively (Table 2). The emission factors obtained from the method described above represent the GHG released from enteric fermentation. The design of the respiration chamber did not allow the removal of poultry excrement during the experiment to ensure the close circulation. Although the poultry excrement was not removed from the respiration chambers, our data from the preliminary experiment showed that, neither CH_4 nor N_2O increased from the excrement residues in the chamber four hours after removal of birds. It is reasonable to speculate that the poultry excrement would not contribute to the methane production since methane formation operates under strictly anaerobic condition (Grabarse et al., 2001; Le Mer and Roger, 2001). The possibility that the poultry excrement contributes to N_2O observed, cannot be ruled out. Nitrous oxide arises from animal wastes occurs during both storage and treatment, by the processes of nitrification and denitrification (Sommers and Dahl, 1999).

The caeca of geese (Chen et al., 2003) and other species of birds (Annison et al., 1968; McBee, 1969; Gasaway, 1976) had been found to be structurally and functionally (Mattocks, 1971; Chen et al., 2002) active in microbial activities. The enteric fermentation emission factors for both CH_4 and N_2O were increased in accordance with the body weight of birds. Due to the length of life cycle, the enteric fermentation factor was the lowest in broiler and the highest in white Roman Geese (Table 2). Another explanation for the difference in emission factors could be the differences in feed conversion efficiency of the two species (Hsu, 1998). It is reasonable to speculate that lowered feed digestibility would lead to the higher rate of enteric fermentation in large intestine with more amounts of undigested feed components. The feed intakes (measured daily) and feed properties (provided by feed suppliers) for three tested species are shown in Table 3. The feed to gain ratio (F/G) of Taiwan country chickens was higher than that of broiler chickens, indicating a lower efficiency of feed conversion. The calculated CH_4/ME ratios for broiler, Taiwan country chickens and geese were 0.002%, 0.007% and 0.04%, respectively. The calculated N_2O/protein-N ratios for broiler, Taiwan country chickens and geese were 0.00004%, 0.015% and 0.016%, respectively. These calculated values suggested that CH_4 and N_2O outputs from broiler chickens were less than two other species tested indicating a better feed efficiency. Further research needs to be conducted to study the effects of digestibility on rate of enteric fermentation. Although IPCC dose not suggest that enteric fermentation is a source of N_2O, very low but detectable levels of N_2O were found in this current study.

Table 3. The average feed consumption, average weight gain, feed efficiencies and feed qualities for broilers, Taiwan country chickens and geese

	Species					
	Broilers		Taiwan country chickens		Geese	
Average feed consumption (kg)	3.022		4.912		16.205	
Average live weight gain (kg)	1.760		1.607		4.502	
F/G	1.717		3.057		3.600	
Feeding interval	0-3 week	3-6 week	0-6 week	6-13 week	0-7 week	7-14 week
ME (kcal/kg)	3,100	3,175	3,100	3,175	3,150	3,240
Crude protein (%)	23	19	23	19	22.5	16
Crude fiber (%)	3.1	2.1	3.1	2.1	6	7

Table 4. Total CH_4 and N_2O emissions by enteric fermentation from different poultry species in Taiwan in 2000

Species (Population, number of birds slaughtered yr^{-1})	CH_4	N_2O
	(mg yr^{-1})	
Broilers (191,202,000)	3.034	0.006
Taiwan country chickens (173,627,000)	14.727	2.838
Geese (6,503,000)	9.50	0.310

According to the IPCC (1996) reference manual, the GHG inventory is calculated by multiplying the default emission factor (kg $head^{-1}$ $year^{-1}$) by the average annual population of livestock (head $year^{-1}$). In the case of poultry, the production cycle does not normally reach one year. If the emission factor is expressed on the bases of average weight of the bird, it will not be reflecting the rapid growth rate of bird. Therefore, it is suggested that the GHG inventory for meat type poultry should be using an emission factor based on the production cycle, multiplied by the total number of birds slaughtered annually. The method to assess greenhouse gas emission from poultry enteric fermentation is applicable to most poultry species. However the reported emission factors are applicable to meat type poultry only.

In the case of layer hens, the emission factors should be divided into two phases: a growing phase and a laying phase. Emissions during the growing phase (pullets) could be treated analogously to meat type poultry and the emission factors should be expressed as per growing period (0-20 weeks). Emission during egg production period (laying hens) should be assessed for the entire year and expressed as per head per year basis. The CH_4/N_2O emission factors estimated for pullets and layers were 3.561/13.33 and 10,610/94.7 (mg $bird^{-1}$ life $cycle^{-1}$), respectively. The calculated CH_4 and N_2O emission from pullets and layers in Taiwan in year 2001 were 372 and 2.86 (Mg $year^{-1}$) (Wang et al., 2002).

The number of broiler chicken, Taiwan country chicken and White Roman Geese slaughtered in year 2000 in Taiwan were 191,202,000, 173,627,000 and 6,503,000, respectively. Based on annual production of poultry in Taiwan in 2000 (COA, 2001), the estimated CH_4 emission from enteric fermentations of broiler chicken, Taiwan country chicken and White Roman Geese would be 3.03, 14.73 and 9.5 Mg $year^{-1}$, respectively in 2000. The estimated N_2O emission from enteric fermentations of broiler chicken, Taiwan country chicken and White Roman Geese would be 0.006, 2.84, and 0.31 Mg $year^{-1}$, respectively in 2000 (Table 4). It is obvious that the total N_2O emission from enteric fermentation was quite low which is the possible reason that N_2O emission from enteric fermentation was not included in IPCC reference manual (1996). The estimated total methane emissions from enteric fermentation of the three species combined were 27.26 Mg in 2000. It comprised of 0.135% of the total emissions from enteric fermentation and 0.03% of the total emissions from agricultural sector calculated from the emission inventory of Taiwan in 2000 (EPA, 2002). Although the calculated total methane emission did not represent a major portion of total contribution, the finding is still very important in terms of accuracy. The emission factors used in emission inventory of Taiwan in 2000 was obtained mostly by referring to existing factors provided by IPCC or by referring to preliminary studies conducted by local scientists. Most factors were overestimated rather than underestimated to account for the uncertainty. Therefore, the actual emission from enteric fermentation and from agricultural sector would be less than the published data, and the calculated total CH_4 emission from enteric fermentation of three estimated species would be more accurate. In addition, the emission from enteric fermentation was overestimated and increased the proportion of avian contribution.

In conclusion, these studies have provided a method for the estimation of GHG emission factors according to the type of poultry over their production period. However, GHG emissions are also affected by quality and quantity of the feed, the energy expenditure of the animal and the environmental temperature (Hironaka et al., 1996; Yan et al., 2000). Therefore, separate emission factors should be estimated in different regions of countries to get accurate GHG emission levels.

ACKNOWLEDGEMENTS

The author thanks S.W. Shieh and S.H. Wang for the assistance with animal management and GC operations for these studies. The author greatly appreciates the research grants supplied by Council of Agriculture in Taiwan (broiler chickens and Taiwan country chickens studies) and National Science Council (White Roman Geese study).

REFERENCES

Annison, E. F., K. J. Kill and R. Kenworthy. 1968. Volatile fatty acids in the digestive tract of the fowl. Br. J. Nutr. 22:207-216.

Chen, Y. H., H. K. Hsu and J. C. Hsu. 2002. Studies on the fine structure of caeca in domestic geese. Asian-Aust. J. Anim. Sci. 15:1018-1021.

Chen, Y. H., S. Y. Wang and H. K. Hsu. 2003. Effects of caecetomy on body weight, intestinal characteristics and enteric gas production in goslings. Asian-Aust. J. Anim. Sci. 16:1030-1034.

COA. 2001. Agricultural Statistics Yearbook 2000. Council of Agriculture, Executive Yuan, Taiwan.

Crutzen, P. J., I. Aselman and I. Seiler. 1986. Methane production by domestic animals, wild ruminants, other herbivorous fauna, and human. Tellus, 38B:271-284.

EPA. 2002. UNFCC National Communication of the Republic of China (Taiwan). Environmental Protect Administration, ROC (Taiwan).

Farrell, D. J. 1972. An indirect closed circuit respiration chamber suitable for fowl. Poult. Sci. 51:683-688.

Gasaway W. C. 1976. Seasonal variation in diet, volatile fatty acids production and size of the cecum of rock ptarmigan. Comp. Biochem. Physiol. 53A:109-114.

Gibbs, M. J. and D. E. Johnson. 1993. Livestock emissions. In: international methane emissions, US Environmental Protection Agency, Climate Change Division, Washington, DC, USA.

Grabarse, W., F. Mahlert, E. Duin, M. Goubeaud, S. Shima, R. Thauer, V. Lamzin and U. Ermler. 2001. On the mechanism of biological methane formation: structural evidence for conformational changes in methyl-coenzyme M reductase upon substrate binding. J. Mol. Biol. 309:315-330.

Hironaka, R., G. W. Mathison, B. K. Kerrigan and I. Vlach. 1996. The effect of pelleting of alfalfa hay on methane production and digestibility by steers. Sci. Total Envir. 180:221-227.

Houghton, J. 1999. Global Warming. Cambridge University Press, Cambridge.

Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Marshall and C. A. Johnson. 2001. Climate Change 2001: The Scientific Basis, Cambridge University Press, Cambridge, UK.

Hsu, A. L. 1998. The nutritional requirement of Taiwan country chicken. Feed and Nutrition Magazine. 98(1):13-21.

IPCC. 1996. IPCC Guidelines for National Greenhouse Gas Inventory. Reference Manual. Vol. 3. Bracknell, UK.

Le Mer, J. and P. Roger. 2001. Production, oxidation, emission and consumption of methane by soils: A review. Eur. J. Soil Biol. 37:25-50.

Mattocks, J. G. 1971. Goose feeding and cellulose digestion. Wildfowl 22:107-113.

McBee, R. H. 1969. Cecal fermentation in the willow ptarmigan. Conder 71:54-58.

Robinson, J. A., W. J. Smolenski, M. L. Ogilvie and J. P. Peters. 1989. *In vitro* total gas, CH_4, H_2, volatile fatty acid and lactate kinetics studies on luminal contents from the small intestine, cecum and colon of the pig. Appl. Envir. Microbiol. 55:2460-2467.

Sommer, S. G. and P. Dahl. 1999. Nutrient and carbon balance during the composting of deep litter. J. Agr. Eng. Res. 74:145-153.

Stevens, C. E. and I. D. Hume. 1995. Comparative physiology of the Vertebrate Digestive System. Cambridge University Press, Cambridge.

Sukahara, T. and K. Ushida. 2000. Effects of animal or plant protein diets on cecal fermentation in guinea pigs (*Cavia porclellus*), rats (*Rattus norvegicus*) and chicks (*Gallus gallus domesticus*). Comp. Biochem. Physiol. A127:139-146.

Wang, S.-Y., W. C. Ma and D. J. Huang. 2002. Estimation of greenhouse gas emission from enteric fermentation of laying hens in Taiwan. J. Chin. Soc. Anim. Sci. 31:221-230.

Yan, T., R. E. Agnew, F. J. Gorden and M. G. Porter. 2000. Prediction of methane energy output in dairy and beef cattle offered grass silage-based diets. Livest. Prod. Sci. 64:253-263.