Greenhouse gases emission and sustainable development of animal agriculture

J. Takahashi

Office of Global Communications and Development, Graduate School of Animal and Food Hygiene, Obihiro University of Agriculture and Veterinary Medicine, Obihiro, Hokkaido, Japan 080-8555

Summary

Atmospheric gases which cause the greenhouse effect are water vapor and atmospheric trace gases such as carbon dioxide, methane, chlorofluorocarbons and nitrous oxide. In general, water vapor is not included in greenhouse gases (GHG) phenomena. The significant GHG attributed to agriculture and animal agriculture is methane, which derives from the activities of methanogens in the enteric fermentation (rumen) and anaerobic fermentation of effluents. It is emitted from organic wastes such as nitrogen fertilizers, and it has 23 times greater greenhouse effect than carbon dioxide, compared to nitrous oxide, which has 310 times greater greenhouse effect than carbon dioxide. The Kyoto Protocol entered into force on February 16, 2005. Regrettably, the United States has not ratified the Kyoto Protocol even though it has the maximum responsibility for GHG emissions. Moreover, the rapid increase of GHG emissions in the economically developing BRIC countries is seriously remarkable. However, the climatic change induced by global warming (attributed to the increase in greenhouse gases) causes enormous damage to agriculture and animal agriculture in the world, and has a serious impact on the rural development in a stable supply of safe food corresponding to the population growth, environmental preservation, hygiene, etc. As for animal effluents, the reproducible energy can be withdrawn as a biogas from anaerobic fermentation, though the principal objective is put on control because it is impossible to recycle methane emitted from enteric fermentation. So far, composting with aerobic fermentation is a major current topic, but the emission of ammonia and nitrous oxide cannot be disregarded. It is necessary to compare the quantitative evaluation of nitrous oxide as a GHG from making compost with anaerobic fermentation.

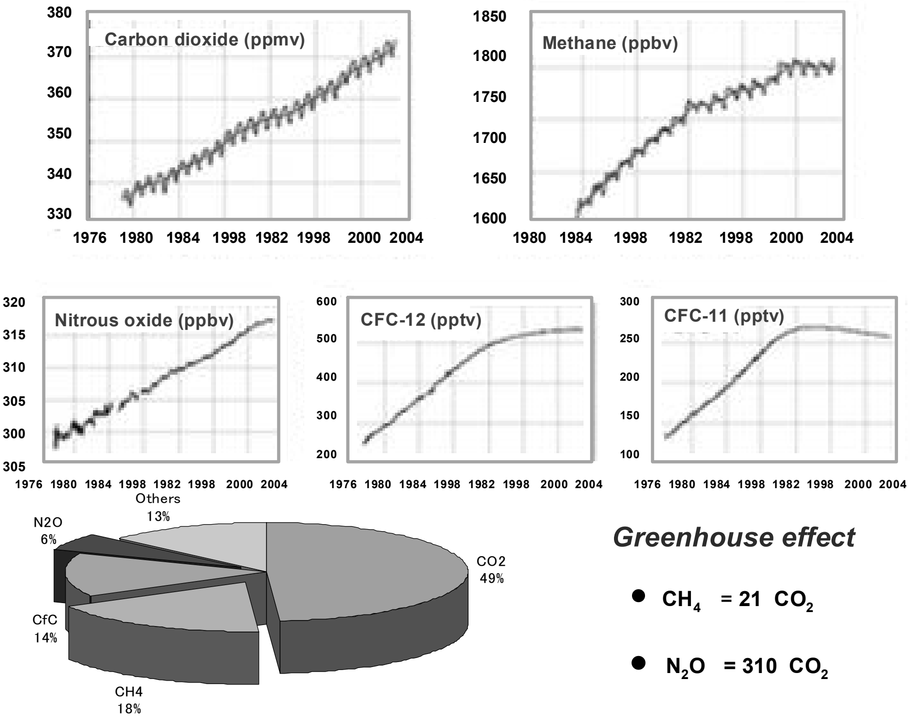
Sharing information and technologies on the control and use of GHG attributed to agriculture and animal agriculture is an imperative issue to education of rural development which contributes much to the sustainable agriculture and animal agriculture.

Key words: global warming, greenhouse gas, nitrous oxide, methane, Kyoto Protocol

Global warming and Kyoto Protocol

Global warming is caused by emissions of carbon dioxide (CO_2) and other greenhouse gases that are emitted primarily by the burning of fossil fuels and the clearing of forests. These gases remain in our atmosphere for decades or even centuries. Global warming is one of the most serious challenges facing us today. To protect the health and economic well-being of current and future generations, we must reduce our emissions of greenhouse gases by using the technology, know-how, and practical solutions already at our disposal. The gases which bring about the greenhouse effect are water vapor and trace gases in atmosphere: CO_2, methane (CH_4), chlorofluorocarbons (CFC-11 and CFC-12), and nitrous oxide (N_2O). The problem with greenhouse gases is an increase in the trace gases in the atmosphere such as CO_2.

Fig. 1 shows the global trend in major long-lived GHG through the year 2002 and their contributions to global warming. These five gases accounts for about 97% of the direct climate changes by long-lived GHG increases since 1750. An increase in CO_2 largely originates from the combustion of fossil fuels following the development of the oil industry in advanced nations after the Industrial Revolution. CH_4 and N_2O, which are related to animal agriculture, maintain an increasingly high growth rate. CO_2 contributes to about the half of the entire greenhouse effect on global warming, followed by CH_4. The concentration of atmospheric CH_4 is only 2ppmv or less and slighter than 350ppmv of carbon dioxide. However, the greenhouse effect of methane is 21-23 times of carbon dioxide, nitrous oxide is 310 times. In Japan targeted reductions of methane and nitrous oxide according to CO_2 equivalent is 0.5% in 6% of 1990 level in Japan (Takahashi, 2006a).



The contribution of greenhouse gases on global warming

Figure 1. Global trends in major greenhouse gases to Jan 2003 and contribution to global warming

As CH_4 is removed from the atmosphere by reacting with radical OH of the troposphere, its longevity (12–17 years) in the atmosphere is shorter than that of CO_2 (50–200 years). The concentration of atmospheric CH_4 at present is twice the value before the Industrial Revolution. The annual rise in concentration has shown a rapid increase of 1.0%–1.3% in the last decade compared with 0.5% for CO_2. However, the absorptivity of infrared rays is already nearly saturated because a large amount of CO_2 exists in the atmosphere and absorption only increases around a narrow zone at about 16μm wavelength. Even if the concentration of CO_2 increases, the absorption ability for infrared rays does not change so much. As for CH_4, the relative absorptivity of the far-infrared radiation is large (about 21 times that of CO_2 for each molecule, and 58 times greater in the weight ratio), and absorptivity is not saturated like CO_2. The absorptivity of the far-infrared radiation by CH_4 rises proportionally with an increase in temperature. Most of the absorption zone of CH_4 is in the 8–13μm range, which does not overlap with the absorption zones of water vapor and CO_2. Therefore, even a little increase of CH_4 concentration in the atmosphere exerts an extremely strong effect on global warming.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (February 16, 2005) is an international treaty on global warming. It is actually an amendment to the United Nations Framework Convention on Climate Change (UNFCCC). Countries which ratified this protocol committed themselves to reduce their emissions of carbon dioxide and five other GHG, or to engage in emissions trading if they maintain or increase emissions of these gases. "The Kyoto Protocol is a legally binding agreement under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990. The goal is to lower overall emissions from six greenhouse gases—carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, HFCs, and PFCs—calculated as an average over the five-year period of 2008–12. National targets range from 8% reductions for the European Union and some others to 7% for the US, 6% for Japan, 0% for Russia, and permitted increases of 8% for Australia and 10% for Iceland."

GHG emission

Figure 2 shows GHG emission rate as a CO_2 equivalent in high-ranking countries. Total emission of GHG as a CO_2 equivalent is 24 billion tons annually. GHG emission in the USA occupies 24% of the total for all countries. The sum of only the top 5 countries is 53% of total emissions. Moreover, a serious problem is that the USA, China and India (members of these top five) did not ratify the Kyoto Protocol.

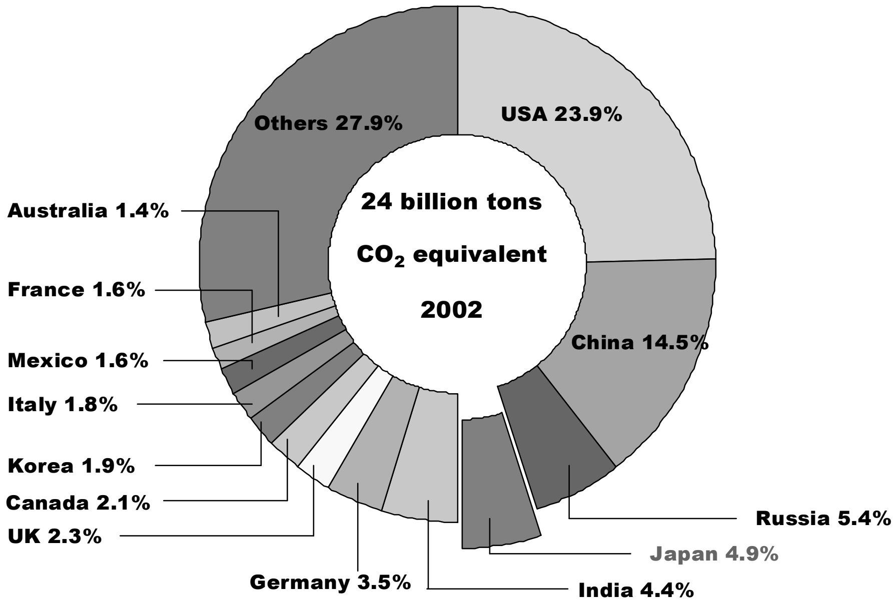


Figure 2. Emission rate of CO_2 in high ranking countries

In Fig. 3 we can see the per capita values for CO_2 emissions from various countries. The upper bar graph shows CO_2 emission (t; CO_2 equivalent) from fossil fuel per person. The USA is also the top contributor even per capita, succeeding Australia, Canada and Saudi Arabia. The lower bar graph shows change ratio of CO_2 emission (%) in 2002 compared to 1990.

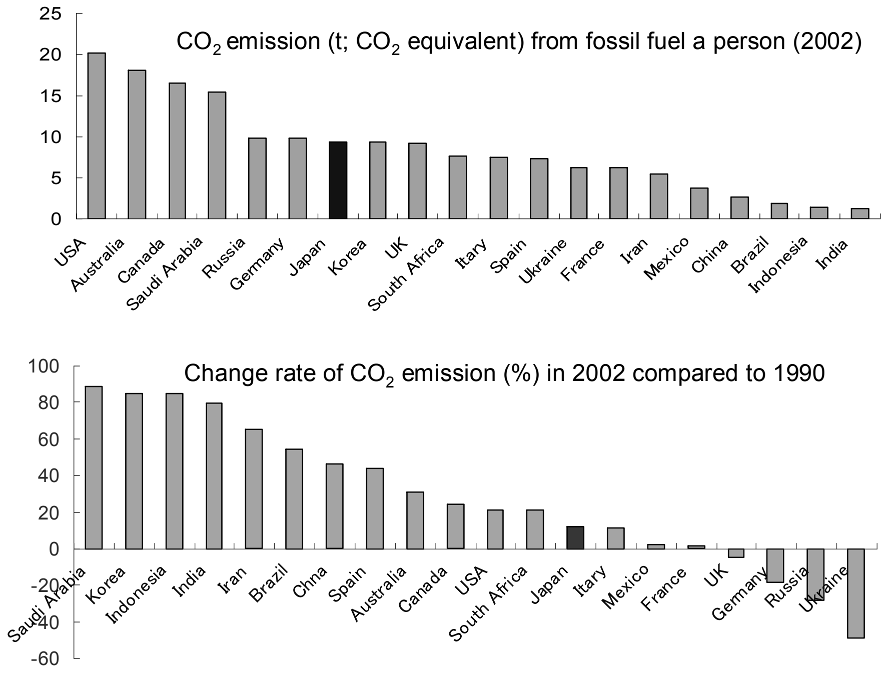


Figure 3. CO_2 emissions per person (upper); changing rate of CO_2 emissions (lower)

The countries where increase rates are large are Saudi Arabia, Korea, Indonesia, Iran and BRIC countries except Russia. Rapid economic development causes an increase in GHG emission. Fig. 4 shows a recent assessment of GHG emission in each sector in Japan. In 2003, GHG emission from transportation and public welfare sectors markedly increased, whereas industry sector suppressed the increment of GHG emission due to persistence of conservation of energy. Regrettably, total GHG emissions in 2003 exceeded 8% more than the level in 1990. Thus, Japan has to abate 14% of GHG of the 1990 level. The important GHG emitted from agricultural sector are CH_4 and N_2O.

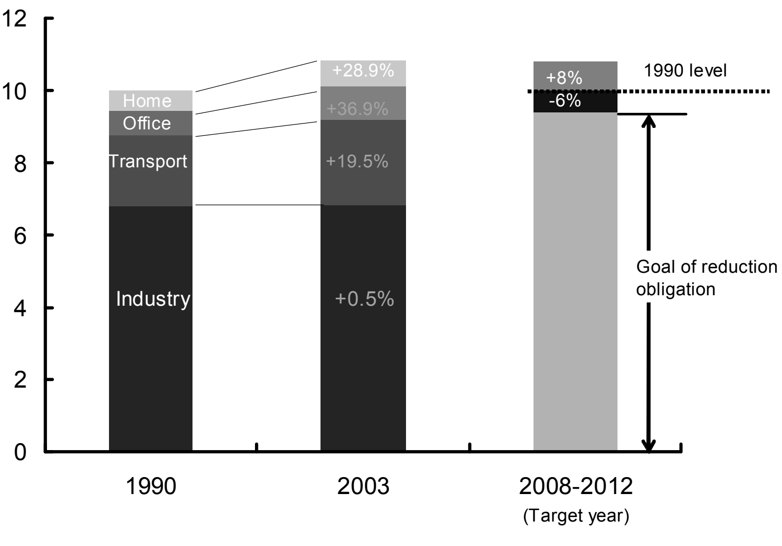


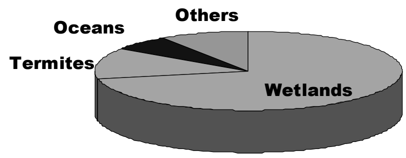
Figure 4. CO_2 emissions in various sectors in Japan.

CH_4 emission from enteric fermentation and effluents

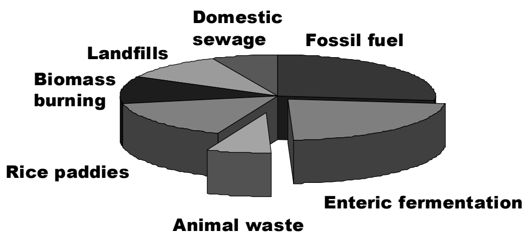
Table 1 shows sources and sinks of atmospheric CH_4. It is possible to divide the sources roughly into natural sources and anthropogenic sources, though each of these sources includes many things. The annual emission of CH_4 in the atmosphere accounts for 535 Tg, according to IPCC (Intergovernmental Panel On Climate Change) report in 1994. Eighty-five teragrams are derived from the rumen fermentation of ruminant animals. When the CH_4 emission of 25 Tg from animal waste are included in the calculation, CH_4 emission from ruminants occupies 20% of total emissions. Another big source (115 Tg) is marshes (wetlands). Sixty percent or more of the amount of CH_4 production is directly attributed to human activities. The enlargement of rice paddies (60 Tg) and livestock numbers is almost proportional to the expansion of human population. This may be the main cause of the increase of CH_4 in the atmosphere. CH_4 produced by rumen fermentation of ruminant animals is emitted into atmosphere by eructation. The ruminant species is a big group, which contains wild giraffe and deer families, etc. including bovine, and even one sub-family (*Bos*) is classified into as many as five genera and 14 species. One target for CH_4 control is milking cows and domesticated beef cattle. The amount of CH_4 emitted by eructation from lactating cows is presumed to be more than 200–400 liters/day though 1,200,000,000 domestic cattle are raised on Earth. One to two 200-L drum-equivalents of pure methane will be emitted into atmosphere by just one milking cow every day.

Table 1. Estimated sources and sinks of methane, (teragrams CH_4 yr-1)

	Individual estimate (Tg)
Sources	
Natural	
Wetlands	115
Termites	20
Oceans	10
Other	15
Anthropogenic	
Fossil fuel	100
Enteric fermentation	**85**
Animal waste	**25**
Rice paddies	60
Biomass burning	40
Landfills	40
Domestic sewage	25
Sinks	
Tropospheric OH	445
Stratosphere	40
Soils	30



Natural sources



Anthropogenic sources

(IPCC 1994)

Table 2 shows estimated methane emission from enteric fermentation of farm animals in Japan based on dry matter intake (DMI). Total emission from enteric fermentation is 0.375 million tons annually. If a dairy farmer keeps 100 lactating cows on his farm, 100–200 liters of 100% CH_4 will be emitted into the atmosphere every day. Dietary fibers are efficiently digested by the enzymes secreted from cellulolytic bacterial cells in the reticulo-rumen (rumen and reticulum) in the huge capacity (200 liters) of rumen, then monosaccharides are decomposed by bacterial fermentation. This microbial metabolism contributes greatly to human nutrition through animal nutrition. However, hydrogen and CO_2 are produced when fibers are digested and fermented by the rumen bacteria. Consequently, a huge amount of CH_4 is produced by methanogens in the rumen; this can be mathematically expressed with simple reaction (Takahashi, 2001, 2002). Although CH_4 is combustible, there is no example of an explosive accident happening because about it is diluted 100-fold with expiration. In other words, it should be impossible to recycle this form of CH_4 (emitted through eructation) as a combustible energy resource, and thus control the quantity of production in the rumen from the viewpoint of the prevention of global warming.

Table 2. Estimated methane emission from enteric fermentation of farm animals in Japan

Animals	DMI (kg)	CH_4 production (l day^{-1} $head^{-1}$)	No. Animals	CH_4 emission (Tg $year^{-1}$)
Dairy cow			1,904,875	0.182
Lactating	15.8	446.5	1,082,000	0.126
Dry	7.5	255.4	332,330	0.022
Replacing	7.9	267.3	490,575	0.034
Beef cattle			2,292,700	0.150
Reproducing	5.8	201.9	696,450	0.037
Fattening				
JB (>1year)	7.3	249.3	565,000	0.037
(<1year)	5.2	181.8	226,550	0.011
HF	9.5	312.2	804,750	0.066
Sheep and goat	0.8	15.9	66,000	< 0.001
Pig		4.2	11,335,000	0.012
Horse		69.0	24,000	< 0.001
Total			15,623,675	**0.345**

From Shibata et al., 1993.

On the other hand, animal effluent, which is another source of methane from animals, corresponds to 22.7% of the total amount of methane emission. This CH_4 can be recycled as an energy resource by anaerobic fermentation processing.

Table 3 shows estimated methane emissions (in gigagrams per year) from animal effluent in Japan. Rapid development of animal agriculture industry in Japan has resulted in a remarkable

Table 3. Estimated methane emissions (Gg yr-1) from animal effluent in Japan

	Dairy cow	Beef cattle	Pig	Laying hen	Broiler	Total
Manure						
Drying	0.0065	0.0004	0.0075	0.0439	0.0093	0.0676
Biogas	0.0415	0.0061	0.1335	0.1228	0.0825	0.3864
Composting	5.3526	0.6316	0.8415	0.8877	1.0956	8.8090
Combustion	0.0160	0.0044	0.0240	0.0920	0.2560	0.3924
Urine						
Biogas	0.0001	-	0.0008	-	-	0.0009
Sludge process	0	-	0	-	-	0
Accumulation	0.1417	0.0082	0.1104	-	-	0.2603
Slurry						
Drying	0.0073	0.0125	0.0029	-	-	0.0227
Biogas	0.0620	0.1613	0.0275	-	-	0.2508
Composting	0.5709	7.1577	0.2508	-	-	0
Accumulation	6.9460	0.1656	0.8096	-	-	7.9212
Total	13.1446	8.1478	2.2085	1.1464	1.4434	**26.0907**

(Source: Haga, 1998)

imbalance between the increased amount of animal effluents and cultivated land area to apply them. An absolute shortage of land area to produce animal feed and animal production highly dependent on imported ingredients of concentrates has amplified the imbalance. Using the CH_4 energy from the domestic animal excreta has already been made the focus of practical use in Japan. Animal effluent causes not only a malodorous problem, but also a eutrophication pollution problem of lakes, ponds, rivers and seawater by nitrate nitrogen, which derives from ammonia nitrogen. In addition, because N_2O, which derives from nitrogen, becomes another greenhouse gas, and becomes the cause of acid rain, too, animal effluent processing is a world issue. That is, the control of the CH_4 emissions from animals is a big problem, which includes the control of CH_4 fermentation in the rumen, the promotion of anaerobic fermentation of effluents to capture methane and use of the digested residue after fermentation as a fertilizer. Furthermore, an efficient conversion of methane energy remains to be elucidated for recycling. The animal husbandry of all countries all over the world is urged to contribute to prevention of global warming by the solution of these problems.

N_2O emission from effluents

Table 4 shows estimated N_2O (nitrogen basis) emissions (Gg year^{-1}) from animal effluent in Japan. Total emission of N_2O-N from animal effluent in Japan was estimated to be 8.7867 Gg year^{-1}. According to the IPCC report (1995), total N_2O-N emission is estimated at 1,500 Gg year^{-1} in the world. Thus, N_2O emission from Japanese animal agriculture accounts for 0.59% of the global emissions. As 0.717 Tg of nitrogen year^{-1} have been excreted from livestock in Japan, this accounts for 0.71% in 101 Tg year^{-1} of total nitrogen excretion from livestock. Relatively lower nitrogen excretion as N_2O can be calculated in Japan. However, excess amount of the untreated effluent resulted in contamination of high nitrate in underground water and pathogens such as Cryptosporidium in surface water. The complaints about the pollution problems in animal agriculture industry have increased with the drastic expansion of animal population in limited areas.

Table 4. Estimated nitrous oxide emission (N_2O-N Gg year$^{-1)}$ from animal effluent in Japan

	Dairy cow	Beef cattle	Pig	Laying hen	Broiler	Total
Manure						
Drying	0.0064	0.0004	0.0156	0.1920	0.0672	0.2816
Biogas	0.0390	0.0050	0.2603	0.5040	0.0428	0.8511
Composting	0.3825	0.0392	0.1245	0.2760	0.5618	1.3840
Combustion	0.0001	0.0000	0.0004	0.0032	0.0146	0.0183
Urine						
Biogas	0.0038	0.0027	0.0375	-	-	0.0440
Sludge process	0.1080	0.0096	2.7600	-	-	2.8776
Accumulation	0.2445	0.0267	0.1725	-	-	0.4437
Slurry						
Drying	0.0116	0.0172	0.0112	-	-	0.0400
Biogas	0.0930	0.2093	0.0998	-	-	0.4021
Composting	0.0653	0.7050	0.0690	-	-	0.8393
Sludge process	0.0240	0.0000	1.2120	-	-	1.2360
Accumulation	0.2835	0.0060	0.0795	-	-	0.3690
Total	**1.2617**	**1.0211**	**4.8423**	**0.9752**	**0.6864**	**8.7867**

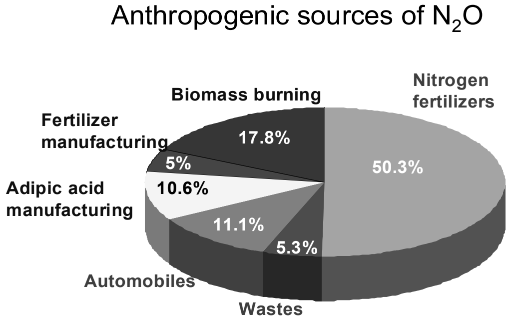
Source: Haga (1998)

Table 5 shows estimated sources and sinks of N_2O, whose emissions from cropped, nitrogen-fertilized (by mineral, manure and legumes) agricultural systems are significant on a global scale (Takahashi, 2006b). Almost half of N_2O emissions from anthropogenic sources were estimated to be attributed to nitrogen fertilizer. N_2O is a strong greenhouse gas, which has a 310-fold stronger greenhouse effect than CO_2.

Table 5. Estimated sources and sinks of nitrous oxide (Tg N_2O year^{-1})

	Range (Tg)
Sources	
Natural	
ocean	1-5
tropical soils	
wet forests	2.2-3.7
dry savannas	0.5-2.0
temperate soil	
forests	0.1-2.0
grasslands	0.5-2.0
Anthropogenic	
cultivated soils	1.8-5.3
biomas burning	0.2-1.0
industrial sources	0.7-1.8
cattle and feedlots	0.2-0.5
Sinks	
Stratosphere	7-13
Soils	?

IPCC (1994)



Carbon and Nitrogen recycling

Though enteric methane emissions must be suppressed due to unavailability of fuel, biogas methane through anaerobic fermentation will be important more and more as an alternative energy for the fossil fuels in the future (Fig. 5). CH_4 and N_2O emissions from effluent could mitigate through C and N recycling (Takahashi et al., 2005). However, loading of CH_4 and N_2O on the environment by composting as conventional effluent management should be assessed quantitatively. For the exploitation of energy through anaerobic fermentation of animal manures and organic wastes, the biogas plant is spreading gradually in animal industries. Promoting the environmentally conscious and sustainable development of agriculture can be realized by solving issues on excess nitrogen problem and creation of recycled energy from animal effluent and organic wastes.

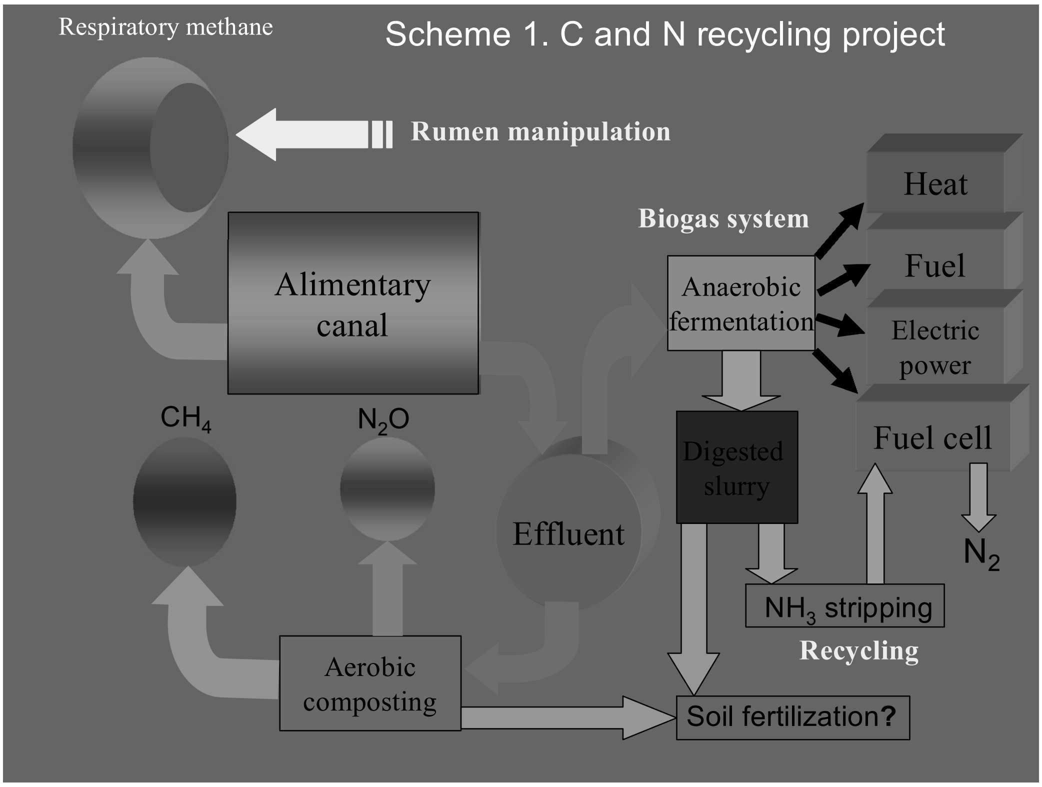


Figure 5. C and N recycling project

References

Haga, K. 1998. Control of greenhouse gases emission (Jpn.), *Reports on the working group for the technology of greenhouse gases control in animal husbandry*, No.3. pp.72–97.

Intergovernmental Panel on Climate Change (IPCC). 1994. Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emissions Scenarios. *In* IPCC Houghton, J.H., L.G. Meria Filho, J. Bruce, H. Lee, B.A. Callander, H. Haites, N. Harris, and K.Maskell (Eds.), *IPCC Special Report 1994*: Cambridge University Press, NewYork, pp.25–27.

Intergovernmental Panel on Climate Change (IPCC). 1995. Climate change 1995: Impacts, adaptations and mitigation of climate change: scientific-technical analyses. *In* Watson, R.T., M.C. Zinyowera, and R.H. Moss (Eds.), *Contribution of Working Group II to the Second Assessment of the Intergovernmental Panel on Climate Change*: Cambridge University Press, Cambridge, pp.747–771.

Shibata, M., F. Terada, M. Kurihara, T. Nishida, and K. Iwasaki. 1993. Estimation of methane production in ruminants. *Anim. Sci. Technol. (Jpn)*64:790–796.

Takahashi, J. 2001. Nutritional manipulation of methanogenesis in ruminants. *Asian-Australasian Journal of Animal Sciences* 14(Special Issue):131–135.

Takahashi, J. 2002. Nutritional manipulation of methane emission from ruminants. *In* Takahashi, J. and B.A. Young (Eds.) *Greenhouse Gases and Animal Agriculture*. Elsevier, Amsterdam, Netherlands. pp.95–103.

Takahashi, J., B. Mwenya, B. Santoso, S. Chetra, K. Umetsu, T. Kishimoto, K. Nishizaki, K. Kimura, and O. Hamamoto. 2005. Mitigation of methane emission and energy recycling in animal agricultural system. *Asian-Australasian Journal of Animal Sciences* 18:1199–1208.

Takahashi, J. 2006a. Emission of GHG from livestock production in Japan. *In* Soliva, C.R., J. Takahashi and M. Kreuzer (Eds.) *Greenhouse Gases and Animal Agriculture: An Update*. International Congress Series 1293. Elsevier, Amsterdam, Netherlands. pp.1–20.

Takahashi, J. 2006b. Sustainable manure management in the nitrogen recycling system. *In*

Currie, L.D. and J.A. Hanly (Eds.) *Implementing sustainable nutrient management strategies in agriculture. Vocational Report No.19*. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. pp.21–28.