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Estimation of methane and nitrous oxide emission from animal production sector in Taiwan during 1990–2000

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Abstract

To investigate the greenhouse gases emissions from the feeding and waste management of livestock and poultry, methane and nitrous oxide emissions were estimated from the local measurement and IPCC guidelines during 1990–2000 in Taiwan. Hog is the major livestock and is followed by goat and cattle, while chicken is the major poultry and is followed by duck and geese. Methane emission from enteric fermentation of livestock was 30.9 Gg in 1990, increased to 39.3 Gg in 1996, and then decreased gradually to 34.9 Gg in 2000. Methane emission from the waste management was 48.5 Gg in 1990, reached the peak value of 60.7 Gg in 1996, and then declined to 43.3 Gg in 2000. In the case of poultry, annual methane emission from enteric fermentation and waste management was 30.6–44.1 ton, and 8.7–13.2 Gg, respectively. Nitrous oxide emission from waste management of livestock was 0.78 ton in 1990, increased to 0.86 ton in 1996, and then decreased to 0.65 ton in 2000. Nitrous oxide emission from waste management of poultry was higher than that of livestock with 1.11 ton in 1990, 1.68 ton in 1999, and 1.65 ton in 2000. There is an urgent need to reduce methane emission from enteric fermentation and recover methane from anaerobic waste treatment for energy in livestock and poultry feeding in Taiwan.

Keywords: Animal feeding; Enteric fermentation; Methane; Nitrous oxide; Waste management

1. Introduction

Global warming induced by increasing greenhouse gases concentrations in the atmosphere is a matter of great environmental concern. Carbon dioxide is the principal greenhouse gas, followed by methane and nitrous oxide in that order. Methane is mostly produced biologically by methanogenic archaea in anaerobic environments. Flooded paddy, enteric fermentation, animal waste management, agricultural waste burning, savannah burning, landfill, sewage treatment, natural wetland and sediment are considered the major sources of methane emissions (Cicerone and Oremland, 1988; Khalil et al., 1991; Lindau et al., 1993; Liu et al., 1996; Yang, 1998; Yang and Chang, 2001; Yang et al., in press).

Methane is a natural by-product of animal digestion through a process referred to as enteric fermentation. Ruminant animals such as cattle, buffalo, sheep and goat are the high sources of methane, whereas the non-ruminant animals such as hog, poultry and horse have much smaller methane emission per animal. The amount of methane produced depends on the type of animal, the amount and the kind of feed it consumes (Kinsman et al., 1995; Lee et al., 2001). In addition, methane emission from animal waste management also contributed to high amount. The anaerobic waste disposal system and the large population of hog explain the large

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amount of methane release (Francisco, 1997; Yang, 1997).

The release of nitrous oxide is increasing in recent years due to intensive agricultural practices and the application of nitrogen fertilizer (Isermann, 1994; Yang et al., in press). Nitrous oxide emission in this section pertains to those releases before the animal wastes are added to soil as fertilizer. These include emission from waste management system other than pasture range and paddock. Nitrous oxide emission is calculated based on animal population, amount of nitrogen excretion, system of waste management and emission factor.

Estimates on greenhouse gas emission from animal feeding and waste management are based on country-specific emission factors, and when the local data were unavailable, the emission factors recommended by IPCC (1997) guidelines were used.

2. Methodology and data

2.1. Livestock and poultry production

The livestock and poultry productions in Taiwan from 1990 to 2000 are adapted from the Taiwan Agriculture Yearbook from 1991 to 2001 (Department of Agriculture and Forest, 1991–2000; COA/ROC, 2001).

2.2. Animal waste production

The amount of waste production of each head depends on variety, feed composition, feeding method, growth stage and management. Therefore, the value is counted by the average of each species. Each head of 60 kg hog daily secretes 2.0 kg feces and 3.75 kg urine with free or fix-feeding methods. Each head daily secretes 27.5 kg feces and 13.5 kg urine for 500 kg body weight of cattle, 0.75 kg feces and 1.75 kg urine for 35 kg body weight of goat. The poultry daily secretes 0.14–0.15 kg waste from chicken, 0.16 kg waste from duck, 0.32 kg waste from geese and 0.33 kg waste from turkey (Yang et al., 1991, 1996, 2003).

2.3. Methane emission factor

Methane emission factors of enteric fermentation and waste management of livestock and poultry are listed in Table 1. Methane emission factors of enteric fermentations were measured in broiler and colorful broiler by Huang and Wang (2000) and in Holstein by Lee et al. (2000). Methane emission factor in hog waste management was calculated by Lin et al. (1989). Other factors were as recommended by IPCC (1997) guidelines.

2.4. Nitrous oxide emission factor

Nitrous oxide emission factors of enteric fermentation and waste management of livestock and poultry are also listed in Table 1. All of them were adapted from the IPCC (1997) guidelines. Waste management includes anaerobic lagoon, anaerobic digestion, daily spread, solid storage and composting, open field feeding and others.

3. Results and discussion

3.1. Methane emission from enteric fermentation

Domestic animal feeding increased sharply in the past 20 years due to policy encouragement, feeding technology improvement and market requirement. Hog, the major domestic livestock in Taiwan, accounted for 93.9% of total livestock feeding in 1990 and 93.3% in 2000. Goat and cattle followed hog. Chicken accounted for 84.6% of total poultry feeding in 1990 and up to 91.2% in 2000. Heads of livestock on farms at the year-end and heads of slaughtered poultry are presented in Table 2. Hog heads reached the maximum of 10 698 366 in 1996, decreased dramatically to 7 966 887 in 1997 because of the foot and mouth disease infection, and then increased slightly after 1999. Heads of buffalo, yellow and hybrid cattle, rabbit, deer and turkey decreased gradually from 1990 to 2000, whereas heads of Holstein, goat, milk goat, chicken and geese increased gradually due to domestic demand.

Methane emission factor of enteric fermentation measured in local and recommended by IPCC guidelines is shown in Table 1. In Taiwan, methane emission factor of enteric fermentation was 8.482×10^{-5} kg/head in each life cycle of colorful broiler and 1.587×10^{-5} kg/head in each life cycle of broiler (Huang and Wang, 2000). Lee et al. (2000) indicated that annual methane emission from enteric fermentation in Holstein lactation cow (body weight 611 ± 56 kg) depended on feed, 137.6 kg with corn silage, 151.5 kg with Napier grass silage and 161.3 kg with Pangola grass haylage; annual carbon dioxide emissions from enteric fermentation were 3760, 5366 and 4051 kg, respectively. However, annual methane emissions from enteric fermentation was 91.3 kg with corn silage, 69.0 kg with Napier grass silage and 88.7 kg with Pangola grass haylage in Holstein dry cow (average body weight 425 kg) and were 61.0, 59.9 and 70.5 kg in growing Heifer (average body weight 275 kg), respectively. Annual carbon dioxide emissions was 3186 kg with corn silage, 2562 kg with Napier grass silage and 2686 kg with Pangola grass haylage in Holstein dry cow and 1902, 1781 and 2051 kg in growing Heifer, respectively (Lee et al., 2001). The average of annual methane emission from enteric fermentation in Holstein lactation

Table 1
Emission coefficient of greenhouse gases in enteric fermentation and waste management

Item	CH_4 emission coefficient (kg/head/year)		N_2O emission coefficient (mg/head/year)				
	Enteric fermentation	Waste management	Anaerobic lagoon	Anaerobic digestion	Daily spread	Solid storage (composting)	Open field feeding
Hog[a]	1.5	5.475[b]	2.08	11.2	0.24	48.0	–
Holstein[a]	56.0	16.0	3.0	12.0	6.0	660.0	120.0
Holstein[c]	149.47	–	–	–	–	–	–
Buffalo[a]	55.0	2.0	–	–	–	–	–
Yellow and hybrid cattle[a]	44.0	1.0	0.0	4.0	4.0	400.0	240.0
Goat[a]	5.0	0.18	1.2	2.4	–	144.0	–
Milk goat[d]	8.0	0.28	1.92	3.84	–	230.4	–
Rabbit[d]	0.143	0.005	0.034	0.069	–	4.116	–
Deer[d]	5.0	0.18	1.2	2.4	–	144.0	–
Horse[d]	18.0	2.08	0.0	4.0	4.0	400.0	240.0
Chicken[a]	–	0.048	–	–	0.006	11.88	–
Colorful broiler[e,g]	8.482×10^{-5}	–	–	–	–	–	–
Broiler[e,g]	1.587×10^{-5}	–	–	–	–	–	–
Layer[f,g]	5.035×10^{-5}	–	–	–	–	–	–
Duck[f,g]	5.239×10^{-5}	0.05	0.0	0.0	6.2×10^{-3}	12.36	–
Geese[f,g]	1.158×10^{-4}	0.110	0.0	0.0	1.43×10^{-2}	28.44	–
Turkey[f,g]	1.158×10^{-4}	0.110	0.0	0.0	1.43×10^{-2}	28.44	–

[a] IPCC (1997).
[b] Lin et al. (1989).
[c] Lee et al. (2000).
[d] The values of milk goat, deer, horse and rabbit were calculated from goat and adjusted by body weight of livestock.
[e] Huang and Wang (2000).
[f] The values of layer, duck, geese and turkey were calculated from broiler and colorful broiler and adjusted by body weight of poultry.
[g] The values were represented in kg/head/life cycle for methane emission coefficient, and mg/head/life cycle for nitrous oxide emission coefficient.

cow, Holstein dry cow and growing Heifer with three feeds was 150.1, 116.6 and 63.8 kg/head, respectively. These values are 2.68, 2.08 and 1.14 times higher than that recommended by IPCC (1997) guidelines. The average of annual carbon dioxide emission from enteric fermentation in Holstein lactation cow, Holstein dry cow and growing Heifer with three feeds was 4392, 2811 and 1911 kg, respectively. Annual enteric fermentations of methane and nitrous oxide of milk goat, rabbit, deer and horse were calculated from goat and adjusted by the body weight, while annual enteric fermentations of methane and nitrous oxide of layer, duck, geese and turkey were estimated from the average value in broiler and colorful broiler with local measurement and adjusted by the body weight.

Annual heads of livestock were calculated from the heads on farms at the year-end and annual heads of poultry were counted from the heads of slaughter. Methane emission from the enteric fermentation of livestock and poultry in Taiwan is illustrated in Table 3. It was calculated from the heads of livestock and poultry times the emission factors. It was found that methane emission from enteric fermentation of animal feeding increased from 30.83 Gg in 1990 to 39.23 Gg in 1996, and then decreased to 34.88 Gg in 2000. Holstein is the largest source of methane emission, contributing 44.0% of the total enteric fermentation in 1990 and gradually up to 58.5% in 2000. Hog contributed 41.7% of the total enteric fermentation in 1990 and 32.2% in 2000. The heads of poultry are numerous, but their body weights are low. In addition, poultry is non-ruminant and non-herbivorous. Therefore, methane emission from enteric fermentation of poultry was below 1% of the total methane emission from animal feeding sector.

3.2. Methane emission from waste management

Feces and urine are separated in livestock, while they are mixed together in poultry. The amount of waste production of each head depends on variety, feeding method, feed formulation, growth stage, managing method and body weight (Hong, 1986a,b; Yang et al., 1991, 1996, 2003). Yang (1994) and Wong et al. (1999) calculated feces production of livestock and poultry in Taiwan, which are presented in Table 4. Annual animal solid waste was 12.5 million ton in 1990, reached a

Table 2
Heads of livestock on farms at the year-end and heads of poultry slaughtered in Taiwan

Item	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Livestock on farms ($\times 10^3$)											
Hog	8565	10 089	9754	9845	10 066	10 509	10 698	7967	6539	7243	7495
Holstein	91	101	111	117	119	124	125	133	134	136	137
Buffalo	22	19	17	16	15	13	11	10	9	9	8
Yellow and hybrid cattle	42	34	31	32	31	28	26	24	23	20	17
Goat	173	176	202	294	311	319	310	315	316	237	202
Milk goat	34	40	45	72	90	112	119	127	129	126	113
Rabbit	161	139	128	112	87	79	76	55	55	43	40
Deer	36	33	30	29	27	24	23	23	22	21	20
Horse	0.9	0.8	0.8	0.8	0.8	0.7	0.6	0.7	0.6	06	0.8
Total	9125	10 630	10 319	10 518	10 746	11 207	11 389	8654	7226	7836	8033
Poultry head slaughtered ($\times 10^3$)											
Chicken	226 556	233 971	257 666	288 243	301 914	319 820	345 509	389 966	389 524	385 563	389 770
Colorful broiler	135 664	126 692	136 831	147 906	149 933	150 756	164 084	180 072	175 215	175 328	173 627
Broiler	74 415	97 504	104 247	123 161	133 495	149 451	159 983	185 280	189 535	185 077	191 202
Layer	16 477	15 775	16 588	17 176	18 486	19 613	21 442	24 614	24 774	25 158	24 948
Duck	39 900	36 295	40 558	45 483	40 886	42 580	41 759	41 156	35 719	35 208	34 099
Tsaiya	1631	1556	1764	1943	1982	2070	2131	2146	2116	2049	2024
Mule-duck	38 269	34 739	38 794	43 540	38 904	40 510	39 628	39 010	33 603	33 195	32 075
Geese	4777	4628	5683	6397	8521	7744	7078	7503	7955	7464	6503
Turkey	758	636	543	521	458	415	398	429	432	488	500
Total	271 991	275 530	304 450	340 644	351 779	370 559	394 774	439 054	433 630	428 723	430 871

Table 3
Estimation of methane emissions from the enteric fermentation of livestock and poultry in Taiwan (ton)

Item	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Livestock	30 828.8	34 081.1	34 782.3	36 816.7	37 442.4	38 916.8	39 227. 3	36 108.8	34 066.7	34 901.2	34 879.8
Hog	12 847.9	15 133.7	14 631.7	14 767.4	15 098.3	15 762.8	16 047.6	11 950.3	9 807.9	10 864.8	11 242.4
Holstein	13 571.6	15 027.6	16 309.4	17 494.4	17 712.6	18 588.8	18 754. 2	19 835.3	20 034.5	20 325.5	20 404.8
Buffalo	1201.2	1024.0	914.3	906.9	820.0	708.6	616.7	528.1	470.6	505.4	427.2
Yellow and hybrid cattle	1828.8	1482.8	1348.8	1411.0	1357.8	1213.4	1162.9	1059.9	1003.5	883.3	766.4
Goat	865.0	878.8	1011.7	1471.2	1554.0	1593.8	1547.5	1577.0	1578.1	1186.5	1012.5
Milk goat	270.2	316.8	363.7	576.0	723.1	894.7	952.4	1017.2	1032.9	1006.7	900.4
Rabbit	46.1	39.7	36.5	31.9	24.7	22.5	21.7	15.8	15.6	12.8	12.0
Deer	182.4	164.2	152.2	143.7	137.2	119.9	113.2	113.1	112.4	106.0	100.1
Horse	15.7	13.5	14.0	14.2	14.6	12.4	11.3	12.2	11.2	10.2	14.0
Poultry	31.9	30.6	33.2	36.3	36.9	37.7	40.3	44.1	43.0	42.8	42.4
Chicken	13.5	13.1	14.1	15.4	15.8	16.2	17.5	19.5	19.1	19.1	19.0
Colorful broiler	11.5	10.8	11.6	12.6	12.7	12.8	13.9	15.3	14.9	14.9	14.7
Broiler	1.2	1.6	1.7	2.0	2.1	2.4	2.5	2.9	3.0	2.9	3.0
Layer	0.8	0.8	0.8	0.9	0.9	1.0	1.1	1.2	1.3	1.3	1.3
Duck	2.1	1.9	2.1	2.4	2.1	2.2	2.2	2.2	1.9	1.9	1.8
Tsaiya	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mule-duck	2.0	1.8	2.0	2.3	2.0	2.1	2.1	2.0	1.8	1.7	1.7
Geese	0.6	0.6	0.7	0.7	1.0	0.9	0.8	0.9	0.9	0.9	0.8
Turkey	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	30 860.6	34 111.7	34 815.4	36 853.0	37 479.2	38 954.5	39 267.7	36 152.9	34 109.7	34 943.9	34 922.2

Table 4
Feces production of livestock and poultry in Taiwan

Item	Daily secrete (kg/head)	Annual amount (kg/head)	Total amount (10^3 ton)										
			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Live-stock			7555	8710	8548	8719	8889	9251	9386	7448	6408	6908	7064
Hog	2.0	730	6253	7365	7121	7187	7348	7671	7810	5816	4773	5288	5471
Holstein	27.5	10 038	911	1009	1110	1175	1190	1248	1259	1332	1345	1365	1370
Buffalo	13.75	5019	110	93	83	83	75	65	56	48	43	46	39
Yellow and hybrid cattle	13.75	5019	209	169	154	161	155	138	133	121	114	101	87
Goat	0.75	273.8	47	48	53	81	85	87	85	86	86	65	55
Milk goat	0.75	273.8	9	11	12	20	25	31	33	35	35	34	31
Rabbit	0.027	9.855	2	2	1	1	1	1	1	1	1	1	1
Deer	0.75	273.8	10	9	8	8	8	7	6	6	6	6	5
Horse	13.75	5019	4	4	4	4	4	3	3	3	3	3	4
Poultry			4895	5010	5730	5975	6277	6446	6898	7223	7363	7405	7252
Chicken													
Colorful broiler	0.14	51.1	1862	1869	2100	2182	2184	2265	2414	2482	2477	2532	2367
Broiler	0.14	51.1	906	984	1142	1257	1392	1456	1596	1770	1882	1845	1816
Layer	0.15	54.75	1249	1275	1327	1370	1524	1588	1756	1881	1928	1964	1973
Duck													
Tsaiya	0.16	58.4	128	128	155	165	166	174	169	184	170	169	170
Mule-duck	0.16	58.4	492	494	704	613	584	590	589	509	502	514	450
Geese	0.32	116.8	216	226	269	356	400	348	353	371	377	351	446
Turkey	0.33	120.45	42	34	32	32	26	25	22	25	28	32	30
Total			12 451	13 720	14 278	14 694	15 166	15 698	16 283	14 671	13 771	14 313	14 316

maximal value of 16.3 million ton in 1996, and decreased to 14.3 million ton in 2000. Hog feces is the major animal waste, accounting for 50.2% of the total animal waste in 1990, 53.7% in 1991, 34.7% in 1998, and 38.2% in 2000. Chicken manure is the next to hog and accounted for 32.3% of the total animal waste in 1990, 45.7% in 1998, and 43.0% in 2000.

Hog (60 kg weight) daily produced 60 l gas containing 60–80% of methane, with the annual methane production of 10.95 kg (Hong, 1986b). Lin et al. (1989) reported that each head of hog daily produced 40 l of wastewater, and generated 31.4 l of methane after anaerobic digestion. The average daily methane emission from hog waste management was 21 l (equivalent to 15.0 g methane), and the annual methane emission was 5.475 kg/head. Methane emission from animal waste management, estimated with local measurement and IPCC recommendation, is listed in Table 5. With IPCC guidelines, methane emission from waste management was 40 317 ton in 1990, had a peak value of 51 251 ton in 1996, decreased to 35 177 ton in 1998 due to the widespread foot and mouth disease, and then increased gradually to 39 033 ton in 2000. Based on the local measurement data, methane emission from waste management was 57 176 ton in 1990, had the highest value 72 985 ton in 1996, decreased to 51 182 ton in 1998, and then increased gradually to 56 277 ton in 2000. High methane emission from hog waste management in Taiwan might be due to the high temperature environment which favors the methanogenesis. It showed that hog waste management, the major source of methane emission, accounted for 82.0% of the total methane emission in 1990, 83.9% in 1991, 69.9% in 1998, and 72.9% in 2000. Chicken manure was the next to hog waste, accounting for 5.8% of the total methane emission in 1991 and 11.3% in 1998.

3.3. Nitrous oxide emission from waste management

In Taiwan, livestock liquid waste is subjected to anaerobic digestion, followed by aeration or facultative treatment to remove BOD, COD and SS, while the solid waste is used as raw materials for composting. Chao (2001) studied the effect of livestock and poultry compost

Table 5
Estimation of methane emission from the waste management of livestock and poultry in Taiwan (ton)

Item	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Livestock	48 481.9	56 968.4	55 296.3	55 919.3	57 154.1	59 672.0	60 724.2	45 883.7	38 082.1	41 953.3	43 325.6
Hog	46 894.0	55 238.0	53 406.0	53 901.0	55 109.0	57 534.0	58 573.0	43 619.0	35 799.0	39 656.0	41 035.0
Holstein	1452.8	1608.6	1769.5	1872.7	1896.1	1989.8	2007.5	2123. 3	2144.6	2175.7	2184.2
Buffalo	43.8	37.2	33.3	33.0	29.8	25.8	22.4	19.2	17.1	18.4	15.5
Yellow and hybrid cattle	41.6	33.7	30.7	32.1	30.9	27.6	26.4	24.1	22.8	20.1	17.4
Goat	31.1	31.6	36.4	53.0	56.0	57.4	55.7	56.8	56.8	42.7	36.5
Milk goat	9.5	11.1	12.7	20.2	25.3	31.3	33.3	35.6	36.2	35.2	31.5
Rabbit	0.8	0.7	0.6	0.6	0.4	0.4	0.4	0.3	0.3	0.2	0.2
Deer	6.6	5.9	5.5	5.2	4.9	4.3	4.1	4.1	4.1	3.8	3.6
Horse	1.8	1.6	1.6	1.6	1.7	1.4	1.3	1.4	1.3	1.2	1.6
Poultry	8694.3	8905.3	10 173.2	10 560.0	11 067.3	11 435.0	12 261.2	12 845.6	13 100.2	13 189.5	12 951.6
Chicken	3695.0	3797.8	4209.2	4431.8	4695.7	4888.2	5305.7	5643. 1	5784.5	5832.6	5880.6
Colorful broiler	1749.0	1755.7	1972.9	2049.5	2051.9	2127.8	2267.2	2331. 1	2326.4	2378.2	2223.3
Broiler	850.6	924.1	1073.1	1180.9	1307.9	1367.9	1498.9	1662.9	1767.4	1732.8	1705.7
Layer	1095.4	1118.0	1163.2	1201.4	1335.9	1392.6	1539.6	1649.1	1690.7	1721.6	1729.5
Duck	531.2	533.1	736.0	665.8	642.2	654.2	648.9	593.2	575.7	582.5	564.1
Tsaiya	110.0	109.9	132.8	141.3	142.2	148.7	144.4	157.3	145.7	144.7	145.7
Mule-duck	421.3	423.2	603.2	524.5	500.0	505.6	504.5	435.9	430.0	437.8	385.2
Geese	203.5	212.4	253.6	335.4	377.0	327.7	332.3	349.8	354.8	330.7	288.1
Turkey	38.4	31.2	29.4	29.5	23.7	22.4	19.8	23.2	25.2	28.8	29.5
Total	57 176.2	65 873.7	65 469.5	66 479.2	68 230.4	71 107.0	72 985.3	58 729.3	51 182.3	55 142.9	56 277.2

Table 6
Estimation of nitrous oxide emission from the waste management of livestock and poultry in Taiwan (kg)

Item	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Livestock	780.9	776.3	765.4	796.5	816.0	850.1	860.9	698.8	611.0	641.9	646.9
Hog	626.9	620.7	600.1	605.7	619.2	646.5	658.2	490.1	402.3	445.6	461.1
Holstein	72.7	80.5	88.6	93.8	94.9	99.6	100.5	106.3	107.4	108.9	109.3
Buffalo	14.2	12.1	10.8	10.7	9.7	8.4	7.3	6.2	5.5	6.0	5.0
Yellow and hybrid cattle	26.9	21.8	19.9	20.8	20.0	17.9	17.1	15.6	14.8	13.0	11.3
Goat	25.5	25.9	29.9	43.4	45.9	47.1	45.7	46.6	46.6	35.0	29.9
Milk goat	8.0	9.4	10.7	17.0	21.4	26.4	28.1	30.0	30.5	29.7	26.6
Rabbit	0.7	0.6	0.5	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.2
Deer	5.4	4.9	4.5	4.3	4.1	3.5	3.4	3.3	3.3	3.1	3.0
Horse	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.5
Poultry	1108.9	1135.3	1297.5	1356.5	1425.2	1462.8	1565.4	1640.6	1673.0	1681.3	1648.3
Chicken	915.0	940.4	1042.3	1097.4	1162.8	1210.5	1313.8	1397.4	1432.4	1444.3	1401.2
Colorful broiler	433.1	434.7	488.5	507.5	508.1	526.9	561.4	577.2	576.1	588.9	550.5
Broiler	210.6	228.8	265.7	292.4	323.9	338.7	371.2	411.8	437.7	429.1	422.4
Layer	271.2	276.9	288.1	297.5	330.8	344.8	381.2	408.4	418.7	426.3	428.3
Duck	131.4	131.8	182.0	164.7	158.8	161.8	160.5	146.7	142.4	144.0	131.3
Tsaiya	27.2	27.2	32.8	35.0	35.2	36.8	35.7	38.9	36.0	35.8	36.0
Mule-duck	104.2	104.7	149.2	129.7	123.7	125.0	124.8	107.8	106.4	108.3	95.3
Geese	52.6	55.0	65.6	86.8	97.5	84.8	86.0	90.5	91.8	85.5	108.7
Turkey	9.9	8.1	7.6	7.6	6.1	5.8	5.1	6.0	6.5	7.5	7.1
Total	1889.8	1911.6	2062.9	2153.0	2241.2	2313.8	2426.3	2339. 4	2284.0	2323.2	2297.2

on nitrous oxide emission from soils. Application of cow, chicken and hog compost released 1.07–1.28%, 0.46–0.60% and 0.79% of nitrogen as nitrous oxide emission, respectively. There is no local measurement on

the nitrous oxide emission from waste management. Therefore, nitrous oxide emission from anaerobic digestion, anaerobic lagoon, daily spread, solid storage and composting, open field feeding and other treatments were adapted from the IPCC guidelines (1997).

Nitrification and denitrification of nitrogen compounds in the wastes and in the soils can release nitrous oxide. Nitrous oxide emission from animal waste management increased from 1890 kg in 1990 to 2426 kg in 1996, and then decreased slightly to 2297 kg in 2000 (Table 6). Chicken waste contributed 48.4% of the total nitrous oxide emission from animal waste management in 1990 and 61.0% in 2000. Hog waste contributed 33.2% in 1990 and 20.1% in 2000.

4. Conclusion

Methane and nitrous oxide emissions from enteric fermentation and waste management in Taiwan are summarized in Fig. 1. Methane emission was distinctly higher than that of nitrous oxide in animal feeding sector. Total methane emission amounted to 88.04 Gg in 1990, 112.25 Gg in 1996, and 91.20 Gg in 2000. Total nitrous oxide emission was only 1.89 ton in 1990, had the highest 2.43 ton in 1996, and down to 2.30 ton in 2000. There is an urgent need to reduce greenhouse gas emissions from animal feeding sector and to recover and utilize methane from animal waste management, because of their impact on global warming.

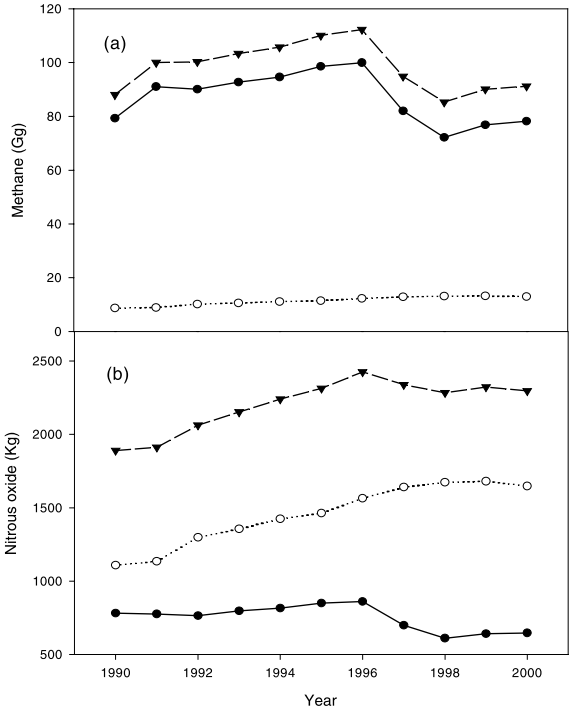

Fig. 1. Greenhouse gases emission from animal feeding sector in Taiwan: (a) methane emission; (b) nitrous oxide emission; (●) livestock; (○) poultry; (▼) total.

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