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Estimation of methane and nitrous oxide emission from livestock and poultry in China during 1949–2003

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Abstract

To investigate the greenhouse gases emission from enteric fermentation and manure management of livestock and poultry industry in China, the present study presents a systematic estimation of methane and nitrous oxide emission during 1949–2003, based on the local measurement and IPCC guidelines. As far as greenhouse gases emittion is concerned among livestock swine is found to hold major position followed by goat and sheep, while among poultry chicken has the major place and is followed by duck and geese. Methane emission from enteric fermentation is estimated to have increased from 3.04 Tg in 1949 to 10.13 Tg in 2003, an averaged annual growth rate of 2.2%, and methane emission from manure management has increased from 0.16 Tg in 1949 to 1.06 Tg in 2003, an annual growth rate of 3.5%, while nitrous oxide emission from manure management has increased from 47.76 to 241.2 Gg in 2003, with an annual growth rate of 3.0%. The total greenhouse gas emission has increased from 82.01 Tg CO_2 Eq. in 1949 to 309.76 Tg CO_2 Eq. in 2003, an annual growth rate of 2.4%. The estimation of livestock methane and nitrous oxide emissions in China from 1949 to 2003 is shown to be consistent with a linear growth model, and the reduction of greenhouse gas emission is thus considered an urgent and arduous task for the Chinese livestock industry.

Keywords: Greenhouse gas; Livestock; Poultry

1. Introduction

The second most important anthropogenic greenhouse gas methane is expected to contribute about 18% of the total global warming gas whereas Co2 has a contribution of 50% attributed over the next 50 years (Milich, 1999). The global abundance of atmospheric CH_4 is about 4850 Tg and the global annual emission is 598 Tg in 1998 (Houghton et al., 2001). The atmospheric concentration of CH_4 has increased to approximately 246% of its pre-industrial concentration (Houghton et al., 1996). A major cause of this rising concentration is the increasing emission, particularly from agricultural activities involving rice , cattle, and other domestic animals (Khalil and Rasmussen, 1994). Livestock farming has become the biggest anthropogenic source of global methane since 1983, contributed 113.1 Tg methane in 1994 (Stern and Kaufman, 1996, 2005).

It is estimated that the total global N_2O emission is about 17.6 Tg N in 1994 (Kroeze et al., 1999), of which approximately 9.6 Tg is due to relatively natural terrestrial and aquatic systems and approximately 8 Tg is derived from anthropogenic sources. Of the anthropogenic N_2O emission, a fraction of 78% is estimated from crop and livestock production in the world (Mosier and Kroeze, 2000).

In the rumen of ruminates—such as cattle, buffalo, sheep, goats and camel—bacteria break down food and generate methane as a by-product. The production rate is affected by factors such as quantity and quality of feed, body weight, age and exercise, and varies among animal species as well as among individuals of the same species. Methane is also emitted during the anaerobic decomposition of organic matter during storage and soil application. Additional gases emitted from manure include ammonia and nitrogen oxides, which contribute to odor and are indirect sources of nitrous oxide. Factors that affect

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methane and nitrous oxide emission from manure include temperature, oxygen level (aeration), moisture and sources of nutrients. These factors are affected, in turn, by manure type (livestock type), diet, storage and handling of manure (pile, anaerobic lagoon, etc.), and manure application (injected, incorporated, etc.). It is important to note that proper manure management is essential for any agricultural operation because improper use of manure can lead to negative impacts on the environment. Effective control of methane and nitrous oxide emission from ruminants can raise ruminants feed utilization, energy conversion rates and productivity.

A time series of methane emissions from Chinese livestock animals was provided by (Khalil et al., 1993), and they covered the years 1900, 1930, 1940, 1950, 1960, and 1965–1988. The emission factors used in this article are inherited almost from the IPCC Tier 1 system (see Table 3). Other former studies of GHG emission in China focused on methane from enteric fermentation and generally on the basis of FAO database (Braatz et al., 1996; Dong et al., 1996). Based upon the method and emission rates available in the China Climate Change Country Study (CCCCS, 1999), methane emissions from livestock was calculated for three animal classes—large animals, sheep and goats, and pigs, which includes both enteric fermentation and manure contributions with an increase from 5.80 Tg in 1990 to 8.55 Tg in 2000 (Streets et al., 2001). Using the Chinese emission factors for cattle, buffaloes, goats, and sheep from Dong et al. (2000), the geographic distribution of CH_4 emissions was examined from livestock in the year of 2000 (Yamaji et al., 2003). Yang and his coworkers investigated the methane and nitrous oxide emissions from the feeding and waste management of livestock and poultry during 1990–2000 in Taiwan (Yang et al., 2003).

IPCC has published useful methods for estimating CH_4 and N_2O emission factors for livestock and poultry using a simplified approach that relies on default emission factors drawn from previous studies (Tier 1) or a somewhat complicated approach that requires country-specific information on livestock and poultry characteristics (Tier 2), as shown in Table 1.

Table 1
The approaches for the livestock methane emission estimation

Livestock type	Emission inventory methods	
	Enteric fermentation	Manure management
Non-dairy cattle	Tier 2	Tier 2
Dairy cattle	Tier 2	Tier 2
Buffalo	Tier 2	Tier 2
Sheep	Tier 2	Tier 1
Goats	Tier 2	Tier 1
Camels	Tier 1	Tier 1
Swine	Tier 1	Tier 2
Horses	Tier 1	Tier 1
Asses	Tier 1	Tier 1
Mules	Tier 1	Tier 1
Rabbits	Tier 1	Tier 1
Chicken	(Not estimated)	Tier 1
Ducks	(Not estimated)	Tier 1
Geese	(Not estimated)	Tier 1
Turkeys	(Not estimated)	Tier 1

The present study presents a systematic estimation of methane and nitrous oxide emission during 1949–2003, based on the local measurement and IPCC guidelines.

2. Methodology and data

2.1. Livestock and poultry production

The livestock and poultry production in China from 1949 to 1989 are mainly adopted from China Animal Husbandry Counts 1949–1989 and China Agriculture Yearbook (from 1991 to 2004), and the database on the FAO website (FAO, 2005) and China Dairy Sector Yearbook 2004 are used as supplement. A specific end-of-year census population in China is collected for the years 1949–2003, and livestock population by sub-category, such as sex and age, are also provided (see Table 2) from 1980 to 1996 (except 1984).

The livestock production has been flourishing in China since 1980, when the meat consumption increased three times with the improving economy and the continuous change in common diet (Chen et al., 2006). According to the Chinese Food and Nutrition Development Program (2001–2010), Chinese consumed 25.3 kg meat products, 11.8 kg egg and 5.5 kg dairy products per capita in 2000. And it is anticipated that the per capita consumption of meat, egg and dairy products in China will reach 32, 18 and 32 kg, respectively, in 2010. Correspondingly, the traditional family feeding style of raising a few chicken and pigs has been replaced by the corporate operations housing thousands of animals to supply the rising market demands in China.

Fig. 1 shows the end-of-year livestock population of the major emitters from 1949 to 2003. As revealed by the figure, the population of swine increased faster than other species before 1992, after that, the increasing demand of the beef, mutton and milk consumption caused by the restructuring of the common diet and high demand for cashmere has lead to the rapid growth of cattle, sheep and goats population. As ruminants are the main source of methane and nitrous oxide, the rising livestock accelerate the emission recent years.

2.2. Emission factors

Methane emission factors of enteric fermentation and manure management, and nitrous oxide emission factors of manure management of livestock and poultry are listed in Table 3. Most of them are calculated following the IPCC (1997) or IPCC (2001) guidelines but specifically modified to suit the Chinese situation. The reminders were adopted directly from the data provided in the IPCC (1997) or IPCC (2001) guidelines.

Table 2
The specific end-of-year census population of livestock and poultry (10^4 head)

Livestock type		1949	…	1995	1996	1997	…	2002	2003
Non-dairy cattle	Female		…	4433	4699	—	…	—	—
	Newborn		…	2392	2665	—	…	—	—
	Other		…	3106	3279	—	…	—	—
	Total	3375	…	9930	10,642	8844	…	9645	9955
Dairy cattle	Female		…	214	219	—	…	—	—
	Newborn		…	104	111	—	…	—	—
	Other		…	99	118	—	…	—	—
	Total		…	417	447	443	…	687	893
Buffalo	Female		…	927	966	—	…	—	—
	Newborn		…	340	367	—	…	—	—
	Other		…	1092	1113	—	…	—	—
	Total	1018	…	2358	2446	2255	…	2272	2228
Sheep	Female		…	6734	7134	—	…	—	—
	Other		…	5993	6135	—	…	—	—
	Total	2622	…	12,726	13,269	12,096	…	14,379	15,733
Goats	Female		…	7325	7929	—	…	—	—
	Other		…	7634	9140	—	…	—	—
	Total	1613	…	14,959	17,068	13,480	…	17,276	18,321
Camels		25	…	35	36	35	…	26	27
Swine		5775	…	44,169	45,736	40,035	…	46,292	46,602
Horses		488	…	1007	1019	891	…	809	790
Asses		949	…	1075	1073	953	…	850	821
Mules		147	…	539	540	481	…	419	396
Rabbits		—	…	14,676	16,547	16,806	…	19,422	19,661
Chicken		—	…	347,455	398,396	312,037	…	398,055	421,475
Ducks		—	…	56,793	64,923	51,211	…	66,035	71,036
Geese		—	…	18,798	21,542	18,018	…	22,777	26,088
Turkeys		—	…	20	18	21	…	19	19

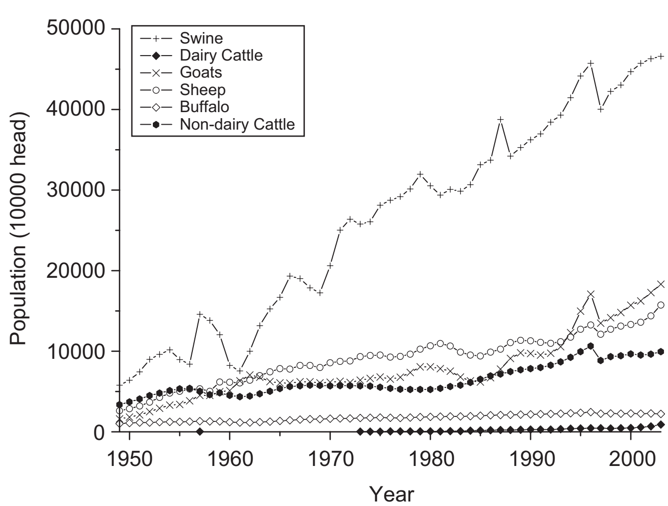

Fig. 1. The specific end-of-year census population of main livestock.

In a technique for measuring methane emitted by grazing ruminant livestock, a calibrated source of inert tracer sulfur hexafluoride (SF_6) is inserted into the rumen of each participating animal prior to collection of "breath" samples for gas analysis (Lassy et al., 2001). In China, with the similar approach on four beef cattle with live weight of 358 ± 30 kg, Fan et al. (2006) suggested the average methane emission factor was 90.97 kg/head/a. Much earlier (Han et al., 1997), four steers (500 ± 50 kg) with permanent rumen and abomasum cannulae were fed different type of diets to arrive at methane production. The results showed the methane emission per animal varied from 44.75 to 54.47 kg/head/a, with an average of 51.59 kg/head/a. An experimental study in 1998 (Sun, 1998) on estimation of methane for 3–7 month old sheep (27 ± 6 kg) showed the emission factor was 7.1–8.9 kg/head/a. The recent estimation of methane emission flux of finishing pigs (66 ± 24 kg) in building (Dong et al., 2006) showed that the average emission factor for swine (both from enteric fermentation and manure management) was 1.2 kg/head/a.

Compared to the experimental data above, the emission factors estimated in this article are dependable.

2.3. Animal waste production

As the average daily volatile solid excretion rate in China is not available, it can only be estimated from feed

Table 3
Emission factors for enteric fermentation and manure management of livestock and poultry

Livestock type		CH_4 emission factors (kg/head/a)						N_2O emission factors (kg/head/a)
		Enteric fermentation				Manure management		Manure management
		This article	Kahlil	IPCC	Yamaji	This article	Kahlil	This article
Non-dairy cattle	Average	54.21	44	—	—	0.92	0.5	0.404
	Female	59.69	—	—	51.3	1.09	—	—
	Newborn	34.92	—	—	28.5	0.55	—	—
	Other	57.53	—	—	53.1	0.9	—	—
Dairy cattle	Average	65.25	44	—	—	8.95	0.5	0.358
	Female	78.49	—	—	70.4	12.51	—	—
	Newborn	39.9	—	—	38.4	5.44	—	—
	Other	57.9	—	—	56.5	7.92	—	—
Buffalo	Average	72.92	50	55	56.3	1.8	0.5	0.408
	Female	87.55	—	—	—	2.27	—	—
	Newborn	48.04	—	—	—	1.07	—	—
	Other	68.23	—	—	—	1.51	—	—
Sheep	Average	5.34	5	5	5.6	0.1	0.5	0.209
	Female	7.42	—	—	—	—	—	—
	Other	3.05	—	—	—	—	—	—
Goats	Average	4.62	5	5	5.4	0.13	0.5	0.231
	Female	6.72	—	—	—	-	—	—
	Other	2.9	—	—	—	—	—	—
Camels		46	58	46	58	1.28	0.5	0.77
Swine		1	1	1	1	1.53	0.5	0.145
Horses		18	18	18	18	1.23	0.5	0.77
Asses		10	10	10	10	0.62	0.5	0.77
Mules		10	10	10	10	0.62	0.5	0.77
Rabbits		0.5	—	—	—	0.01	—	0.005
Chicken		—	—	—	—	0.015	—	0.005
Ducks		—	—	—	—	0.01	—	0.005
Geese		—	—	—	—	0.02	—	0.015
Turkeys		—	—	—	—	0.11	—	0.048

intake levels

$$VS = \frac{GE \times (1 - DE) \times (1 - ASH)}{18.45},$$

where VS is the volatile solid excretion per day on a dry-matter weight basis (kg-dm/day), GE is estimated daily average feed intake in MJ/day, DE is digestible energy of the feed in percent and ASH is ash content of the manure in percent.

3. Results and discussions

3.1. Methane emission from enteric fermentation

The feeding domestic animal increased sharply in the past 55 years due to constant government encouragement for producing more meat, introducing efficient feeding technology introduced and the ever increasing market demand. Swine, the major domestic livestock in China, particularly in southern China, accounted for 36.1% of the total livestock fed in 1949 and 40.4% in 2003, followed by sheep, goats and cattle. Chicken accounted for 82.2% of the total poultry fed in 1960 and 81.3% in 2003. The end-of-year livestock and poultry population are presented in Table 2.

In 1996, swine reached the second peak with amount of 4.57×10^8 head/a, which decreased dramatically to 4.00×10^8 in 1997 because of the foot and mouth epidemic. After that, swine production recovered gradually and reached the maximum of 4.66×10^8 in 2003. Similar trend appeared in production of sheep, goats, non-dairy cattle (primarily yellow cattle), dairy cattle (primarily Holstein), buffalo and poultry except rabbits, which increased continuously because of the sharply rising demand. The animals mainly used for transportation, involving camels, horses, asses and mules, declined in the last decades due to the reduced demand for their transportation usage in modern society (Tables 4–6).

Following the IPCC (1997) and IPCC (2001) guidelines, methane emission factors are calculated using Tier 2 approach for 1980–1996 (except 1984). The end-of-year population of cattle, buffalo, sheep and goats are provided

Table 4
Methane emission from enteric fermentation (Tg)

Livestock type		1949	…	1995	1996	1997	…	2001	2002	2003
Non-dairy cattle	Female	—	…	2.65	2.80	—	…	—	—	—
	Newborn	—	…	0.84	0.93	—	…	—	—	—
	Other	—	…	1.79	1.89	—	…	—	—	—
	Total	1.83	…	5.28	5.62	4.79	…	5.17	5.23	5.4
Dairy cattle	Female	—	…	0.17	0.17	—	…	—	—	—
	Newborn	—	…	0.04	0.04	—	…	—	—	—
	Other	—	…	0.06	0.07	—	…	—	—	—
	Total	—	…	0.27	0.28	0.29	…	0.37	0.45	0.58
Buffalo	Female	—	…	0.81	0.85	—	…	—	—	—
	Newborn	—	…	0.16	0.18	—	…	—	—	—
	Other	—	…	0.75	0.76	—	…	—	—	—
	Total	0.74	…	1.72	1.79	1.64	…	1.65	1.66	1.62
Sheep	Female	—	…	0.50	0.53	—	…	—	—	—
	Other	—	…	0.18	0.19	—	…	—	—	—
	Total	0.14	…	0.68	0.72	0.65	…	0.73	0.77	0.84
Goats	Female	—	…	0.49	0.53	—	…	—	—	—
	Other	—	…	0.22	0.27	—	…	—	—	—
	Total	0.07	…	0.71	0.80	0.62	…	0.75	0.80	0.85
Camels		0.01	…	0.02	0.02	0.02	…	0.01	0.01	0.01
Swine		0.06	…	0.44	0.46	0.40	…	0.46	0.46	0.47
Horses		0.09	…	0.18	0.18	0.16	…	0.15	0.15	0.14
Asses		0.09	…	0.11	0.11	0.10	…	0.09	0.08	0.08
Mules		0.01	…	0.05	0.05	0.05	…	0.04	0.04	0.04
Rabbits		—	…	0.07	0.08	0.08	…	0.10	0.10	0.10
Chicken		—	…	—	—	—	…	—	—	—
Ducks		—	…	—	—	—	…	—	—	—
Geese		—	…	—	—	—	…	—	—	—
Turkeys		—	…	—	—	—	…	—	—	—
Total		3.04	…	9.53	10.11	8.80	…	9.52	9.75	10.13

with subcategories during these years. Using the data, the specific average emission factors are estimated. The methane emission factors from enteric fermentation of non-dairy cattle, dairy cattle, buffalo, sheep and goats are 54.21, 65.25, 72.92, 5.34 and 4.62 kg/head/day, respectively, while the recommended factors of IPCC (1997) guidelines are, respectively, 44, 56, 55, 8 and 5 kg/head/day. Rest of the factors are directly adopted from IPCC (1997) and IPCC (2001) guidelines.

Methane emission from enteric fermentation is 3.04 Tg in 1949, increases to 10.13 Tg in 2003, with an annual growth rate of 2.2% (see Fig. 2). Non-dairy cattle contributed the most in methane emission from enteric fermentation (60.2% of the total in 1949 and down to 53.3% in 2003), which surpassed the emission from swine although swine population is larger. Methane emission of dairy cattle increased very sharply, doubled within the last 5 years. Fig. 2 also shows the methane emission from enteric fermentation in China compared with the data of the United States (EPA, 2005). The animal methane emissions in the US which decreased slowly are all less than those in China which increased sharply from 1980 to 2003.

3.2. Methane emission from manure management

Similarly, the CH_4 emission factors from manure management of non-dairy cattle, dairy cattle, buffalo and swine are, respectively, 0.92, 8.95, 1.80 and 1.53 kg/head/day. Rest of the factors are adopted from the IPCC (1997) and IPCC (2001) guidelines, and adjusted by climate distribution and manure management system type.

Methane emission from manure management is 0.16 Tg in 1949, reaches 1.06 Tg in 2003, an annual growth rate of 3.5% (see Fig. 3). Swine contributed the most in methane emission from manure management (56.3% of the total in 1949 and 67.0% in 2003). Compared with the US methane emission from manure management, the methane emission in China is much smaller, as suggested by Dong et al. (1996) swine manure management usually adopted solid storage (45%) and drylot (45%), and neither of these are anaerobic.

3.3. Nitrous oxide emission from manure management

The N_2O emission factors from manure management of non-dairy cattle, dairy cattle, buffalo and swine are

Table 5
Methane emission from manure management (Tg)

Livestock type		1949	…	1995	1996	1997	…	2001	2002	2003
Non-dairy cattle	Female	—	…	0.05	0.05	—	…	—	—	—
	Newborn	—	…	0.01	0.01	—	…	—	—	—
	Other	—	…	0.03	0.03	—	…	—	—	—
	Total	0.03	…	0.09	0.09	0.08	…	0.09	0.09	0.09
Dairy cattle	Female	—	…	0.03	0.03	—	…	—	—	—
	Newborn	—	…	0.01	0.01	—	…	—	—	—
	Other	—	…	0.01	0.01	—	…	—	—	—
	Total	—	…	0.05	0.05	0.04	…	0.05	0.06	0.08
Buffalo	Female	—	…	0.02	0.02	—	…	—	—	—
	Newborn	—	…	0.00	0.00	—	…	—	—	—
	Other	—	…	0.02	0.02	—	…	—	—	—
	Total	0.02	…	0.04	0.04	0.04	…	0.04	0.04	0.04
Sheep	Female	—	…	—	—	—	…	—	—	—
	Other	—	…	—	—	—	…	—	—	—
	Total	0.00	…	0.01	0.01	0.01	…	0.01	0.01	0.02
Goats	Female	—	…	—	—	—	…	—	—	—
	Other	—	…	—	—	—	…	—	—	—
	Total	0.00	…	0.02	0.02	0.02	…	0.02	0.02	0.02
Camels		0.00	…	0.00	0.00	0.00	…	0.00	0.00	0.00
Swine		0.09	…	0.68	0.70	0.61	…	0.70	0.71	0.71
Horses		0.01	…	0.01	0.01	0.01	…	0.01	0.01	0.01
Asses		0.01	…	0.01	0.01	0.01	…	0.01	0.01	0.01
Mules		0.00	…	0.00	0.00	0.00	…	0.00	0.00	0.00
Rabbits		—	…	0.00	0.00	0.00	…	0.00	0.00	0.00
Chicken		—	…	0.05	0.06	0.05	…	0.06	0.06	0.06
Ducks		—	…	0.01	0.01	0.01	…	0.01	0.01	0.01
Geese		—	…	0.00	0.00	0.00	…	0.00	0.00	0.01
Turkeys		—	…	0.00	0.00	0.00	…	0.00	0.00	0.00
Total		0.16	…	0.97	1.00	0.88	…	1.00	1.02	1.06

calculated, respectivey, to be 0.404, 0.358, 0.408 and 0.145 kg/head/day. Rest of the factors are adopted from IPCC (1997) and IPCC (2001) guidelines, and adjusted by climate distribution and manure management system type.

Nitrous oxide emission from manure management is 47.76 Gg in 1949, increases to 241.2 Gg in 2003, with an annual growth rate of 3.0% (see Fig. 4). Swine contributed the most in N_2O emission from manure management (17.5% of the total in 1949 and up to 28.0% in 2003) followed by goats, non-dairy cattle and sheep. Fig. 4 also shows the N_2O emission from domestic livestock in China compared with the US. The US emission data ranged from 1980 to 2003 and the emission are finally surpassed by China in 1998 after a reversal during 1995–1997. During all these years, the methane emission decreased slowly in US while it increased sharply in China.

3.4. Further discussion

The IPCC developed the Global Warming Potential (GWP) concept to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to other gases. The GWP of a greenhouse gas is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas (IPCC, 2001). The GWP values of methane and nitrous oxide used in this article are 21 and 310, respectively (100-year time horizon, IPCC, 1996). So, we can summarize the methane and nitrous oxide together with the GWP as the unified measure.

Methane and nitrous oxide emission from domestic livestock in China increases from 82.01 Tg CO_2 Eq. in 1949–309.76 Tg CO_2 Eq. in 2003 as shown in Fig. 5 with an annual growth rate of 2.4%. Compared with that in US, more methane and nitrous oxide have been released in China than in the US after 1989.

If taking demographic factors into account, the conclusion would be very different. Fig. 6 illustrates the per capita emission variation, which shows that the emission per capita along the China time series increased very slowly and the data are almost steady at 200 kg CO_2 Eq. per capita. Though the gross emission in China

Table 6
Nitrous oxide emission from manure management (Gg)

Livestock type		1949	…	1995	1996	1997	…	2001	2002	2003
Non-dairy cattle	Female	—	…	—	—	—	…	—	—	—
	Newborn	—	…	—	—	—	…	—	—	—
	Other	—	…	—	—	—	…	—	—	—
	Total	13.64	…	40.12	42.99	35.73	…	38.53	38.96	40.22
Dairy cattle	Female	—	…	—	—	—	…	—	—	—
	Newborn	—	…	—	—	—	…	—	—	—
	Other	—	…	—	—	—	…	—	—	—
	Total	—	…	1.49	1.60	1.58	…	2.03	2.46	3.20
Buffalo	Female	—	…	—	—	—	…	—	—	—
	Newborn	—	…	—	—	—	…	—	—	—
	Other	—	…	—	—	—	…	—	—	-
	Total	4.16	…	9.62	9.98	9.2	…	9.22	9.27	9.09
Sheep	Female	—	…	—	—	—	…	—	—	—
	Other	—	…	—	—	—	…	—	—	—
	Total	5.49	…	26.65	27.79	25.33	…	28.46	30.11	32.94
Goats	Female	—	…	—	—	—	…	—	—	—
	Other	—	…	—	—	—	…	—	—	—
	Total	3.73	…	34.56	39.43	31.14	…	37.51	39.91	42.32
Camels		0.19	…	0.27	0.27	0.27	…	0.21	0.2	0.2
Swine		8.36	…	63.96	66.23	57.97	…	66.24	67.03	67.48
Horses		3.75	…	7.76	7.85	6.86	…	6.36	6.23	6.08
Asses		7.31	…	8.27	8.26	7.34	…	6.79	6.54	6.32
Mules		1.13	…	4.15	4.16	3.70	…	3.36	3.23	3.05
Rabbits		—	…	0.78	0.88	0.89	…	1.01	1.03	1.04
Chicken		—	…	17.89	20.51	16.06	…	21.1	20.49	21.7
Ducks		—	…	2.84	3.25	2.56	…	3.44	3.31	3.56
Geese		—	…	2.88	3.30	2.76	…	3.60	3.49	3.99
Turkeys		—	…	0.01	0.01	0.01	…	0.01	0.01	0.01
Total		47.76	…	221.3	236.5	201.4	…	227.9	232.3	241.2

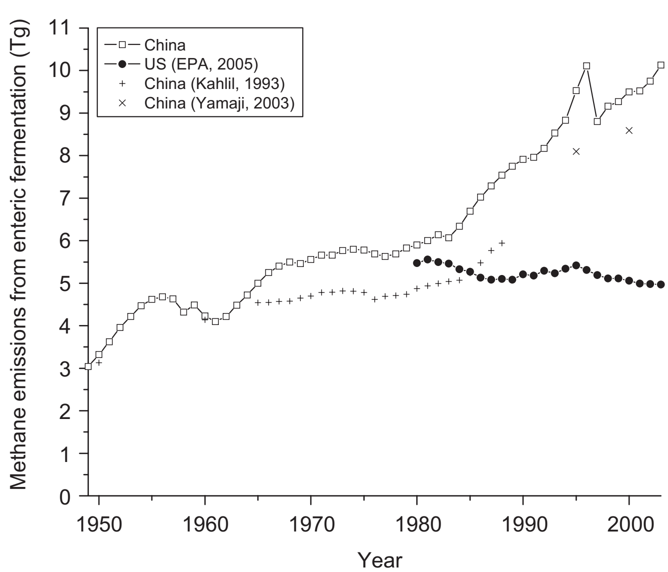

Fig. 2. Methane emission from enteric fermentation (Tg CH_4).

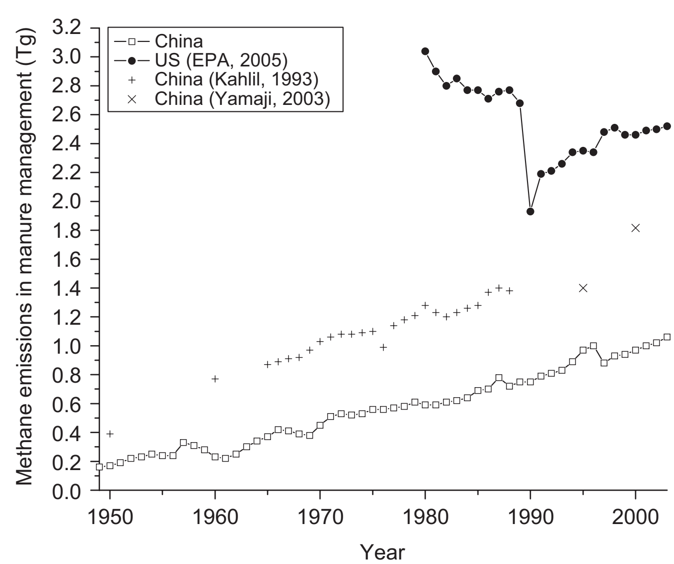

Fig. 3. Methane emission from manure management (Tg CH_4).

is greater than that in the US after 1989, emission per capita in China is only about one quarter of that in the US.

Finally, we developed a formula to predict the future methane and nitrous oxide emission based on linear regression of collected emission data. Fig. 7 gives the

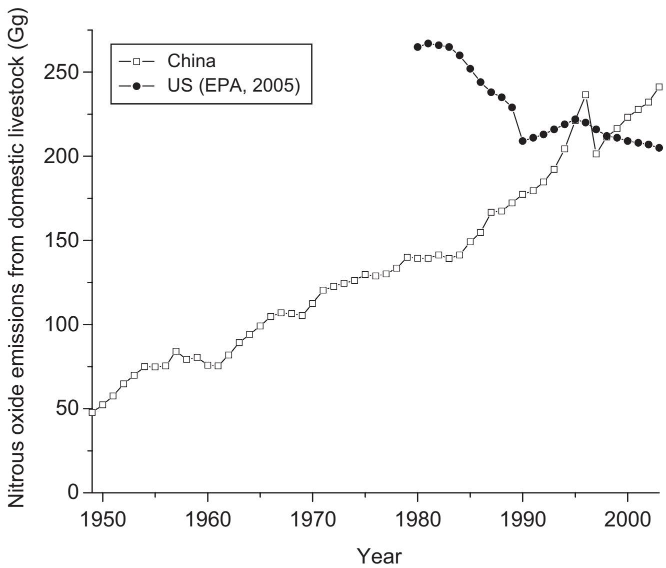

Fig. 4. Nitrous oxide emission from domestic livestock (Gg N_2O).

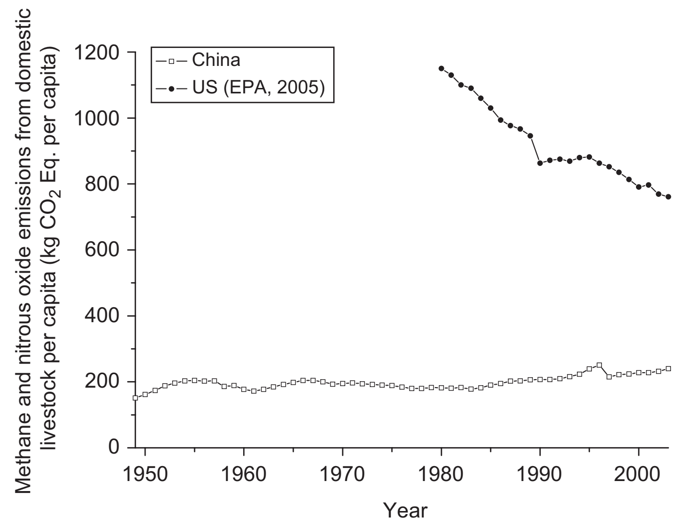

Fig. 6. Methane and nitrous oxide emission from domestic livestock per capita (kg CO_2 Eq. per capita).

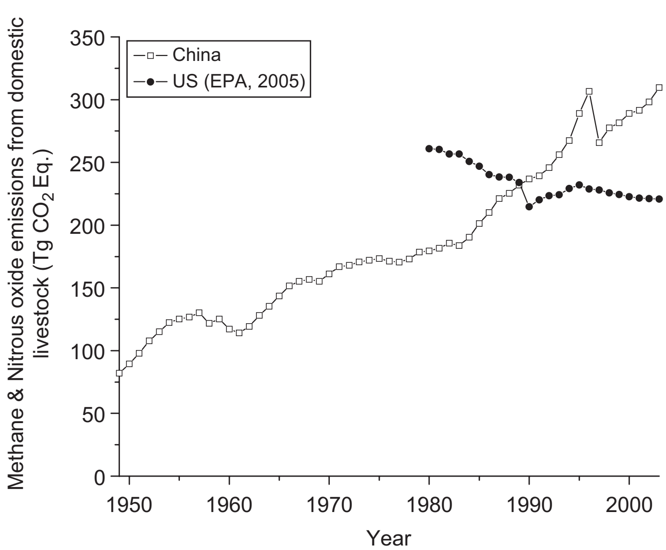

Fig. 5. Methane and nitrous oxide emission from domestic livestock (Tg CO_2 Eq.).

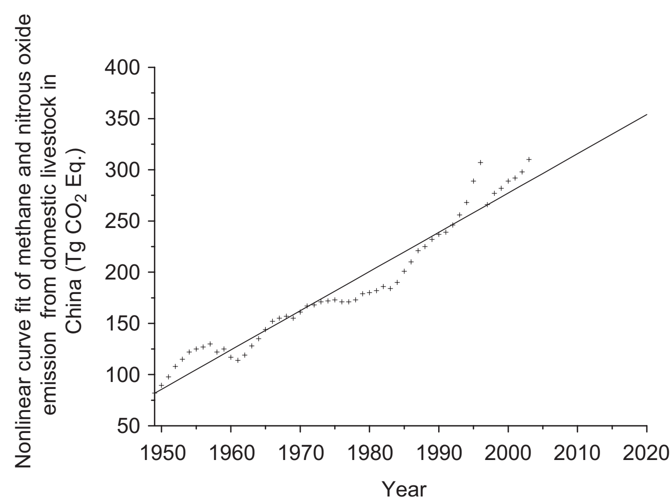

Fig. 7. Linear fitting of methane and nitrous oxide emission from domestic livestock in China (Tg CO_2 Eq.).

fitting of methane and nitrous oxide emission from domestic livestock in China based on a linear growth model (with $R^2 = 0.945$)

$$\text{Emission} = 81.9 + 3.83(\text{year} - 1949),$$

revealing that the natural resources such as pasture and feed have not been a limiting factor for this growth in the past. Should the mechanism remain unchanged, we can estimate that in 2010, 2020 and 2050, methane and nitrous oxide emission from domestic livestock in China would be 316, 354 and 469 Tg CO_2 Eq., respectively.

4. Concluding remarks

Due to the exponential growth associated with the livestock methane and nitrous oxide emission in China from 1949 to 2003, reduction of greenhouse gas emission is considered an arduous and urgent task for the Chinese livestock industry. It was believed (Han et al., 1997) that increasing the fine fodder proportion is an effective way.

On 1 July 2006, if all goes as planned the Chinese government would have passed the Livestock Law, stipulating that methane-generating pit or other manure management devices should be used in breeding grounds. The methane emission factors of such manure management approaches are higher, but the emitted gas will be used as a substitute for fire wood or coal, even electricity in country, which should significantly reduce the greenhouse effect.

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References

Braatz, V.B., Jallow, P.B., Molnár, S., Murdiyarso, D., Perdomo, M., Fitzgerald, F.J. (Eds.), 1996. Greenhouse Gas Emission Inventories. Kluwer Academic Publishers, Dordrecht, The Netherlands.

CAE, 1991–2005. China Agriculture Yearbook (from 1991–2004). China Agriculture Publishing House.

CAHC, 1990. China Animal Husbandry Counts 1949–1989. China Economics Publishing House.

CCCCS, 1999. China Climate Change Country Study. Tsinghua University Press, Beijing, China.

CDSY, 2005. China Dairy Sector Yearbook 2004. China Agriculture Publishing House.

Chen, G.Q., Jiang, M.M., Chen, B., Yang, Z.F., Lin, C., 2006. Emergy analysis of Chinese agriculture. Agriculture, Ecosystems and Environment 115, 161–173.

Dong, H.M., Lin, E., Li, Y., Rao, M., Yang, Q., 1996. An estimation of methane emissions from agriculture activities in China. Ambio 25, 292–296.

Dong, H.M., He, Q., Li, Y., Tao, X., 2000. Livestock production and CH_4 emission from enteric fermentation of domestic livestock in China. In: Proceedings of the IGES and NIES Workshop on GHG Inventories for Asian Pacific Region, Hayama, pp. 50–60.

Dong, H.M., Zhu, Z.P., Tao, X.P., Shang, B.in., Kang, G.H., Zhu, H.S., Shi, Yi., 2006. Measurement and analysis of methane concentration and flux emitted from finishing pig house. Transactions of the CSAE 22, 123–128 (in Chinese).

EPA, 2005. Inventory of US greenhouse gas emission and sinks 1990–2004. 〈http://www.epa.gov/climatechange/emissions/downloads 06/06_Complete_Report.pdf〉

Fan, Xia, Dong, H.M., Han, L.J., 2006. Experimental study on the factors affecting methane emission of beef cattle. Transactions of the CSAE 22, 179–183 (in Chinese).

FAO, 2005. FAO statistical databases. 〈http://faostat.fao.org〉

Han, J.F., Feng, Y.L., Zhang, X.M., Mo, Fang, Zhao, G.Y., Yang, Y.F., 1997. Effects of fiber digestion and VFA in the rumen on the methane production in steers of different type of diets. Chinese Journal of Veterinary Science 17, 278–280 (in Chinese).

Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A., Maskell, K. (Eds.), 1996. Climate Change 1995: The Science of Climate Change. Cambridge University Press, Cambridge, UK.

Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Xiaosu, D. (Eds.), 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge.

IPCC, 1997. Revised 1996 IPCC guidelines for national greenhouse gas inventories. 〈http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm〉.

IPCC, 2001. Good practice guidance and uncertainty management in national greenhouse gas inventories. 〈http://www.ipcc-nggip.iges.or.jp/public/gp/english/〉.

Khalil, M.A.K., Shearer, M.J., Rasmussen, R.A., 1993. Methane sources in China: historical and current emission. Chemosphere 26, 127–142.

Khalil, M.A.K., Rasmussen, R.A., 1994. Global emission of methane during the last several centuries. Chemosphere 29, 833–842.

Kroeze, C., Mosier, A.R., Bouwman, L., 1999. Closing the global N_2O budget: a retrospective analysis 1500–1994. Global Biogeochemical Cycles 13, 1–8.

Lassy, K.R., Walker, C.F., McMillan, A.M.S., Ulyatt, M.J., 2001. On the performance of SF_6 permeation tubes used in determining methane emission from grazing livestock. Chemosphere Global Change Science 3, 367–376.

Milich, L., 1999. The role of methane in global warming: where might mitigation strategies be focused. Global Environmental Change 9, 179–201.

Mosier, A., Kroeze, C., 2000. Potential impact on the global atmospheric N_2O budget of the increased nitrogen input required to meet future global food demands. Chemosphere—Global Change Science 2, 465–473.

Stern, D.I., Kaufman, R.K., 1996. Estimates of global anthropogenic methane emission 1860–1993. Chemosphere 33, 159–176.

Stern, D.I., Kaufman, R.K., 2005. Annual estimates of global anthropogenic methane emission: 1860–1994. 〈http://cdiac.ornl.gov/ftp/trends/ch4_emis/ch4.dat〉.

Streets, D.G., Jiang, K., Hu, X.H., Sinton, J.E., Zhang, X.Q., Xu, D.Y., Jacobson, M.Z., Hansen, J.E., 2001. Recent reductions in China's greenhouse gas emissions. Science 294, 1386–1387.

Sun, J.Y., 1998. A study on estimation of methane and its energy value for 3–7 months old little-fat-tail sheep. Acta Zoonutrimenta Sinica 10, 27–34 (in Chinese).

Yang, S.S., Liu, C.M., Liu, Y.L., 2003. Estimation of methane and nitrous oxide emission from animal production sector in Taiwan during 1990–2000. Chemosphere 52, 1381–1388.

Yamaji, K., Ohara, T., Akimoto, H., 2003. A country-specific, high-resolution emission inventory for methane from livestock in Asia in 2000. Atmospheric Environment 37, 4393–4406.