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Greenhouse gas emissions from the enteric fermentation and manure storage of dairy and beef cattle in China during 1961–2010

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ABSTRACT

Due to the expanding dairy and beef population in China and their contribution to global CH_4 and N_2O budgets, a framework considering changes in feed, manure management and herd structure was established to indicate the trends of CH_4 and N_2O emissions from the enteric formation and manure storage in China's beef and dairy production and the underlying driving forces during the period 1961–2010. From 1961 to 2010, annual CH_4 and N_2O emissions from beef cattle in China increased from 2.18 Mt to 5.86 Mt and from 7.93 kt–29.56 kt, respectively, while those from dairy cattle increased from 0.023 to 1.09 Mt and 0.12 to 7.90 kt, respectively. These increases were attributed to the combined changes in cattle population and management practices in feeds and manure storage. Improvement in cattle genetics during the period increased the bodyweight, required dry matter intake and gross energy and thus resulted in increased enteric CH_4 EFs for each category of beef and dairy cattle as well as the overall enteric EFs (i.e., Tier 1 in IPCC). However, for beef cattle, such an impact on the overall enteric EFs was largely offset by the herd structure transition from draft animal-oriented to meat animal-oriented during 1961–2010. Although the CO_2-eq of CH_4 and N_2O from manure storage was less than the enteric emissions during 1961–2010 in China, it tended to increase both in beef and dairy cattle, which was mainly driven by the changes in manure management practices.

1. Introduction

Dairy and beef cattle have been the most important type of animal in terms of CH_4 from enteric fermentation emissions and nitrous oxide (N_2O) from manure management emissions (de Araujo et al., 2007; Beauchemin et al., 2010) since livestock farming has become the largest anthropogenic source of global methane (CH_4) in the 1980s (FAO, 2006; Stern and Kaufman, 2005). China was a high-emission country (Yamaji et al., 2003); during the period 1890–1998, the cumulative enteric CH_4 emission from China dairy and beef cattle industries contributed approximately 3.73% of the total enteric CH_4 from the global cattle industry, and the cumulative N_2O emission from China dairy and beef cattle industries contributed approximately 3.17% of the total N_2O emission from global cattle industry (de Araujo et al., 2007). In addition, China's dairy population and total dairy milk production have increased by approximately 24 and 58 times, respectively, from 1961 to 2010, while beef slaughters and beef cattle in stock increased 78 times and by 70%, respectively, which had led to a 104 times increase in beef meat. Therefore, dairy and beef industries of China are believed to be a substantial contributor to the global greenhouse gas emissions.

Due to the large contribution of CH_4 and N_2O emissions from China's dairy and beef industries, efforts characterizing these emissions have been conducted from different aspects. For example, Khalil et al. (1993) estimated CH_4 emissions from Chinese livestock during the period 1900–1988 using the IPCC Tier 1 methodology to evaluate the historical changes of agricultural and industrial contributions to national GHGs. Enteric CH_4 emissions from livestock in China were estimated on the basis of the FAO database (Braatz et al., 1996; Dong et al., 1996) to discuss the GHGs contribution of different regions to the global budget. Streets et al. (2001) also calculated the enteric and manure CH_4 emissions from livestock in China but based upon the method and emission rates available in the China Climate Change Country Study (CCCCS, 1999) to indicate the total GHGs emission trend during 1990–2000 in China. In addition, Yamaji et al. (2003) examined the geographic distribution of CH_4 emissions from livestock in the year 2000 using the Chinese emission factors for cattle, buffaloes, goats, and sheep from Dong et al. (2000).

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Several issues related to the accuracy of estimation of CH_4 and N_2O emissions from the dairy and beef industries in China arose from the previous efforts. Firstly, different methodologies for distinct perspectives were used in those studies, which made a direct comparison between the studies difficult (Ominski et al., 2007). Secondly, in most cases default emission factors for CH_4 and N_2O by the IPCC methodology in 1996 or 2006 were used, whereas impacts of the changes in cattle genetics, feeds and manure management practices, i.e., the driving forces, on emissions from China's dairy and beef industries were not indicated. Thirdly, contributions of cattle categories such as lactating cows, heifers, bulls and steers to the total emissions were not estimated separately even though their emission factors (EFs) varied greatly (de Araujo et al., 2007). Therefore, uncertainties in the emission estimates were large due to the many complexities involved and the lack of accurate data (Oenema et al., 2005), and clarification of greenhouse gases emissions from the beef and dairy industries in China is essential to aid decision-making processes (Kanemoto et al., 2014). Therefore, it is necessary to evaluate the characteristics of CH_4 and N_2O emissions from dairy and beef production and to assess the impacts of policy, feed management, manure management, and evolution of animal type on CH_4 and N_2O emissions.

In this study, by considering the changes in feed, manure management and herd structure of China's beef and dairy cattle during 1961–2010, a framework capable of calculating direct CH_4 and N_2O emissions from major sources in dairy and beef operations including enteric fermentation and manure storage systems based on IPCC methodology in 2006 (IPCC, 2006) was established to (1) indicate the historical changes in CH_4 and N_2O emissions from dairy and beef industries in China as well as their intensities on the basis of dairy and beef products and (2) understand the impacts of changes in driving forces on CH_4 and N_2O emissions during the period 1961–2010.

2. Methodologies

Direct CH_4 and N_2O emissions (including enteric fermentation and manure storage) from dairy and beef production in China during the period 1961–2010 were calculated to characterize the evolution of total emissions, or emission factors. Fig. 1 shows the flow chart of calculating CH_4 and N_2O emissions from dairy and beef production in China. Calculation details are shown below.

2.1. Estimation of herd structures

As shown in Fig. 1, accurately estimating the proportion of herd structure and their respective body weights (BWs) and daily gains (DGs) was the first step. FAO Framework (2010) was used in this study to estimate herd structures of beef and dairy cattle and other parameters by using the data of beef meat, milk production and cattle populations during 1961–2010 obtained from the DATASET of FAO. Beef cattle were firstly separated into two classes termed as slaughters and in-stock cattle, then with the FAO framework the herd structures of dairy or beef cattle in stock were separated into four categories including adult male and female cattle, male and female replacements, and the respective proportion and average BW for each category were provided (Fig. S-1, Supplementary material).

2.2. Determination of DMI, CPI and GE

With the determination of BWs of different categories of dairy and beef cattle in Section 2.2, required terms for the calculation of CH_4 and N_2O emissions including daily dry matter intake (DMI), crude protein intake (CPI), animal feed nitrogen intake (FNI) and the gross energy intake (GEI) for each category of dairy and beef cattle in China were obtained from the Feedings Standards of Beef Cattle (2004) and the Feedings Standards of Dairy Cattle (2004) established with feeding experiments conducted in China, which had been thoroughly compared with other regions worldwide and the representativeness of covering China's situation was discussed. Meanwhile, instead of using province-specific parameters, the national level parameters for different animal categories were adopted for calculations as this study focused on the CH_4 and N_2O emissions at national level (Section 5, Supplementary material).

2.3. Determination of VS and N in excreta

Volatile solids (VSs) from DMI and N excretion from FNI were the sources of CH_4 and N_2O emissions from dairy and beef manure. The total VS of dairy and beef production during 1961–2010 were estimated with IPCC methodology in 2006 (IPCC, 2006), whereas the total manure N from the dairy industry in China was calculated as a proportion of the feed N input according to the study by Gao et al. (2013) and Bai et al. (2013) in which the empiric metabolic equations of determining the N excretion of dairy beef cattle were evaluated (Section 3 in Supplementary material).

2.4. Proportioning contributions of different manure management practices

Methane and N_2O emissions from manure storage are important contributors to total emissions and are strongly influenced by manure management practices. It was reported by Zhao (2009) that collectable manure was managed with three practices including drylot[1] storage, composting (static pile) and anaerobic digestion (biodigester) (Fig. 2). In the early 1960s, approximately 12% of raw manure from the dairy and beef industries was uncollectable, while the rest, i.e., collectable manure, was handled as composting and drylot storage, accounting for 72% and 28% of the collectable manure, respectively. In the late 1980s, it was reported that approximately 9% of the collectable manure was used for biogas production (i.e., anaerobic digestion), and the same proportions of composting and drylot storage as in 1960s were assumed. While in the late 2000s, a survey by Zhao (2009) indicated that the composting and anaerobic digestion of manure accounted for 40% and 8% of the collected manure, respectively, while the remainder was stored in drylot. The manure treated according to all three practices was applied to fields as organic fertilizers. To fill the data gap regarding the proportions of the various manure management practices over the last 50 years, it was assumed that the proportions changed linearly with time. Some uncertainty with these proportions would exist although the magnitude cannot be fully examined.

2.5. Calculation of CH_4 and N_2O emissions

For enteric CH_4 emission factors (kg head^{-1} yr^{-1}) from dairy and beef cattle, Eq. (7) in Supplementary material (Section 4) was used, where the CH_4 conversion factor Y_m for both dairy and beef cattle was estimated as 6.5%. With the estimation of VS and the proportion of different manure management practices, manure CH_4 emission factors (kg head^{-1} yr^{-1}) from the manure storage of the beef and dairy industries in China during the period 1961–2010 were calculated with the IPCC Tier 2 methodology (IPCC, 2006) (Section 6 in Supplementary material). Whereas for N_2O emissions, part of the collectable manure N was lost to the environment mainly via ammonia (NH_3) and nitric oxide (NO) emissions, and the remaining N in manure formed the basis of N_2O emissions. Ammonia and NO emission factors (kg head^{-1} yr^{-1}) for drylot storage, composting systems and liquid digestate in storage ponds were obtained from Misselbrook et al. (2000, 2010). By using the emission factors expressed as a percentage of N excretion from the IPCC methodology Tier 2 in 2006 (IPCC, 2006), N_2O emissions from each type of manure handling system were added together to obtain the total N_2O emission of the entire manure management sector (Section 5, Supplementary material).

3. Results

3.1. Changes in feeds and manure management of dairy and beef production

Dry matter intakes (DMI) and GEIs of all types of cattle were estimated with the inclusion of annual average BW, daily gain (DG) and production level. Fig. 3 shows the trends of annual DMI for each category in beef and dairy herd during 1961–2010. For dairy cattle, the annual DMI for female adults remained stable during 1961–1977 and then followed by a fast increase in 2010, with an average annual increase of about 1.6% during 1977–2010 (Fig. 3B). For all other categories of dairy herd, the fastest DMI increase occurred between 1990 and 2010, with annual increases of 3.1% for female replacements, 3.6% for male adults and 4.7% for male replacements. In contrast to dairy cattle, the DMI for stock beef cattle and slaughters increased at relatively lower rates, but for

[1] A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically (IPCC, 2006). This is the major cattle operation in China due to its simplicity and low financial investment.