Front. Agr. Sci. Eng. 2023, 10(2): 226–233 https://doi.org/10.15302/J-FASE-2023486

REVIEW

GREENHOUSE GAS EMISSIONS FROM LIVESTOCK IN CHINA AND MITIGATION OPTIONS WITHIN THE CONTEXT OF CARBON NEUTRALITY

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KEYWORDS

animal husbandry, emission reduction solutions, feed improvement, greenhouse gases emission, manure management

HIGHLIGHTS

- Livestock is major greenhouse gas source in agriculture in China.
- Greenhouse gas emissions in livestock shows an upward trend during 1994 to 2014.
- Main mitigation options are improving productivity, feed quality and manure recycling.
- Strengthening monitoring and standards is necessary for capacity building.

Received December 8, 2022;
Accepted January 28, 2023.

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GRAPHICAL ABSTRACT

ABSTRACT

Animal husbandry is a major source of greenhouse gas (GHG) emissions in agriculture. Mitigating the emissions from the livestock sector is vital for green development of agriculture in China. Based on National Communication on Climate Change of United Nations, this study aims to investigate the characteristics of GHG emissions of animal husbandry during 1994 to 2014, introduce major emission reduction technologies and their effectiveness, and investigate options for emission reduction for the livestock sector in China. It proposes that control of pollution and carbon emissions can be realized through increased animal productivity, improved feed quality and recycling of animal manure. This paper thus concludes with suggestions of green and low-carbon development of animal husbandry, including the research and development of new technology for emission reduction and carbon sequestration of the livestock sector, enhancement of monitoring and evaluation, and establishment of emission reduction and carbon sequestration standards.

1 INTRODUCTION

Carbon neutrality refers to a balancing process, in which the amount of carbon dioxide removal equals that emitted from anthropologic activities during a given period of time. CO_2 emissions can be offset in the form of afforestation, or reduced through energy conservation and emission reduction. In the broader sense, it also refers to the net zero greenhouse gas (GHG) emissions[1]. China aims to reach peak CO_2 emissions before 2030 and carbon neutrality before 2060. This is a major strategic decision made by the Communist Party of China (CPC) Central Committee when considering both domestic and international situations. It is an internal requirement for implementing the new development philosophy, building a new development pattern and promoting high-quality development, and a solemn commitment that China has made to the world[2]. In March 2022, Secretary General of Central Committee of the Communist Party of China published an article on the *Qiushi Journal*, GHG emission mitigation and carbon sequestration in agriculture and rural areas is an important and promising measure, which calls for scientific modeling and monitoring, achievable plans and strong regulatory measures.

Food systems are responsible for a third of global anthropogenic GHG emissions[3]. Xu et al.[4] estimated the global GHG emissions of food system, and found that GHG emissions of food from animal sources are twice as much as that from plant sources. Livestock accounts for up to half of the technical mitigation potential of the agriculture, forestry and land-use sectors, through management options that sustainably intensify livestock production, promote carbon sequestration in rangelands and reduce emissions from manures, and through reductions in the demand for animal products[5]. Accelerating efforts in animal husbandry is crucial to achieving carbon emission reduction and sequestration in agricultural and rural areas, and for achieving the goal of carbon neutrality in China.

The 2020 “Opinions of the General Office of the State Council on the High-quality Development of Animal Husbandry” clearly emphasized the need to reutilize livestock and poultry manure to facilitate circular development of crop production and animal husbandry, establish an evaluation system for green development of animal husbandry, and increasing deployment of supporting technologies for green development. It also highlighted the necessity for improving regulations for standardized livestock farming and management, and providing demonstrations of standards-based livestock farming. This paper presents the current status of GHG emissions of animal husbandry in China, reviews the GHG emission reduction technology of methane and nitrous oxide emissions status from both enteric fermentation and manure management, and provides general measures and suggestions for emission reduction, in order to provide guidance for the green and low-carbon development of animal husbandry in China.

2 GREENHOUSE GAS EMISSION STATUS OF LIVESTOCK SECTOR IN CHINA

According to “2006 IPCC Guidelines for National Greenhouse Gas Inventories”, livestock production can result in three sources of GHG emissions: CH_4 from enteric fermentation in livestock, and CH_4 and N_2O from manure management. Based on the IPCC Guidelines, China systematically reported its GHG emissions from livestock sector in 1994, 2005, 2010, 2012 and 2014, the Chinese government then submitted relevant emission results to the United Nations as part of China’s National Greenhouse Gas inventories. Currently, the Ministry of Ecology and Environment is organizing the estimation of GHG emissions of livestock sector from 2015 to 2020. Table 1 lists the changes of total GHG emissions from animal husbandry in China from 1994 to 2014, which shows an upward trend. The emissions increased from 246 Mt CO_2 eq in 1994 to 345 Mt CO_2 eq in 2014, increasing by 40.6%. The greatest increase was from 1994 to 2005, followed by a slowdown from 2005 to 2014. Comparing the total emission data of agriculture for each year, the proportion of GHG emissions from livestock ranged from 37.6% to 48.7%.

Of the possible emission sources, enteric fermentation was the main source of GHG emissions from animal husbandry in China, accounting for 58.4% to 66.1% of total livestock emissions, varying between years. This was followed by N_2O

Table 1 GHG emissions from livestock in China during 1994–2014 (Mt CO_2 eq)

Emission sources	1994	2005	2010	2012	2014
CH_4 from enteric fermentation	214	235	217	206	207
CH_4 from manure management	18	51	64	68	66
N_2O from manure management	14	70	73	79	72
Total	246	356	354	353	345
Proportion of total agricultural emissions (%)	40.7	48.7	42.8	37.6	41.6

emissions from manure management of 19.6% to 22.4%. CH_4 emissions from manure management accounted for 14.3% to 19.2%. From the perspective of interannual changes, CH_4 emissions from enteric fermentation had a downward trend, while CH_4 and N_2O emissions from manure management had a rising trend (Fig. 1). The emissions of different animal species varied greatly, and the main emissions came from beef cattle and swine. Beef cattle were the top sources of GHG emissions, being between 29.9% and 36.9% of total emissions from livestock, followed by swine ranging from 20.2% to 22.9% (Fig. 2). The other livestock species each represented less than 10% of the total. From the perspective of interannual changes, the emissions of swine, sheep and goats increased annually, while those of beef cattle and buffalo tended to decline and had low variability. In terms of emission source composition, beef cattle produced the largest amount of emissions, with CH_4 emissions from enteric fermentation as the main source. Swine were the second largest emitters, with emissions mostly arising from the manure management.

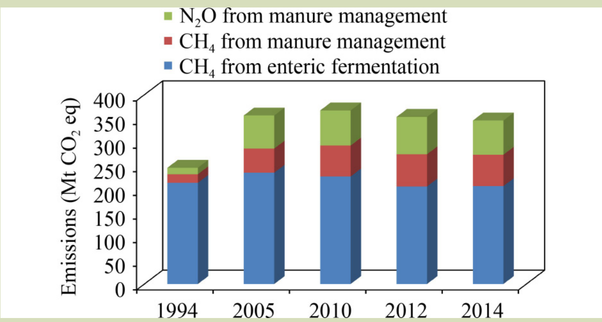

Fig. 1 Emissions from different greenhouse gas sources in livestock production during 1994–2014.

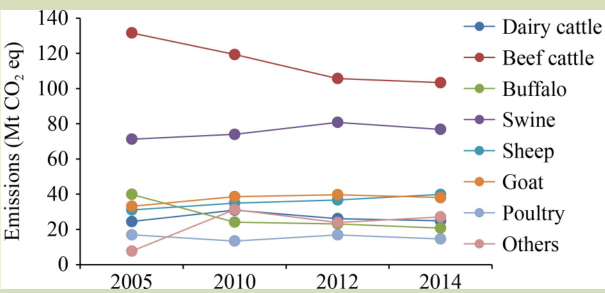

Fig. 2 Greenhouse gas emissions from different livestock species between 2005 and 2014.

3 MAJOR TECHNOLOGIES FOR EMISSION MITIGATION IN ANIMAL HUSBANDRY

3.1 CH_4 mitigation technology for enteric fermentation

Enteric fermentation in ruminant is the main source of GHG emissions from livestock production. Nearly 2% to 15% of energy of feed intake is lost via CH_4 emissions[6]. The oxygen-limited environment of rumen converts feed to a large amount of CH_4 through the action of enzymes and microbial transformation. Taking effective measures to reduce enteric CH_4 emissions of ruminant will not only reduce large amount of GHG emissions from livestock but also improve the production efficiency of animal husbandry. Hristov et al.[7] proposed to improve feed quality for ruminants as one of the most effective ways to reduce CH_4 emissions. Higher production efficiency could decrease energy demand and the amount of feed needed to produce the same amount of animal products.

3.1.1 Regulation of nutrient composition of rations

Arndt et al.[8] suggested that emissions of CH_4 could be reduced by 12% by reducing the percentage of concentrate in feed rations, improving feeding performance and reducing the maturity of straw. CH_4 emissions from enteric fermentation could also be mitigated through higher feed quality by lessening the ratio of neutral detergent fiber to non-fibrous carbohydrates and addition of soluble carbohydrates. The high-quality feed may also push up voluntary feed intake, shorten the time of feed in the rumen and reduce the proportion of diet converted to CH_4[9].

3.1.2 Optimization of the types of dietary feed

Silage made from whole maize plants, sorghum, cassava residue and alfalfa silage can be used to replace other roughage (usually cereal straw) in ruminant rations to improve feed digestibility and reduce rumen CH_4 emissions. High-quality silage can be used as a mitigation alternative for reducing enteric emissions and increasing productivity, thus decreasing GHG emissions per unit of product. For example, Åby et al.[10] found that feeding silage has a greater potential for emission reduction in beef cattle production, and the emission intensity is expected to drop by nearly 17%. Improving roughage quality can also significantly lower CH_4 emissions from animal enteric fermentation. Na et al.[11] compared the effects of different straw roughage and maize silage roughage on enteric CH_4 emissions from dairy cows. The results showed that with the same roughage to concentrate ratio, CH_4 emissions of maize silage rations was 20% lower than with of straw-based rations.

3.1.3 Use of feed supplements

Supplements such as probiotics, plant extracts, prebiotics, enzymes and nitrates are added to feed to break the ecological balance of gastrointestinal microorganisms, inhibit microbial activity of rumen and reduce CH_4 emissions, but their effects often decline substantially in the long-term due to adaptation of the rumen microbial ecosystem[5]. Of all kinds of feed supplements, adding a certain amount of fat or fatty acid may change the pattern of rumen fermentation. Wang et al.[12] adopted meta-analysis of the effect of various feed supplements used in beef cattle farming, including fat, monensin, electron receptors and inhibitors, on the control of enteric CH_4 emissions of beef cattle. They found that the comprehensive emission reduction efficiency of various feed supplements to CH_4 was 12.7%. Addition of fats in diets is one of the dietary options recognized to decrease enteric CH_4 emissions, but the inhibitory response of fats on CH_4 production depends on concentration, type and fatty acid composition of fats, and the overall nutrient composition of the diet[13,14].

3.2 Greenhouse gas emission mitigation technology for manure management

Organic compounds in animal waste mainly include carbohydrates and nitrogenous compounds. Carbohydrates are easily decomposed to produce CH_4 under anaerobic conditions by methanogenesis. Nitrogenous compounds are mainly proteins and can be decomposed into amino acids under the action of enzymes. Amino acids can be further decomposed through nitrification or denitrification under aerobic or anaerobic conditions. These processes lead to final product nitrates and N_2O byproduct. CH_4 and N_2O emissions are inevitable in the process of storage and treatment of animal waste, which are two of the major sources of agricultural GHG emissions. The most effective mitigation measures include reasonable design of animal housing, application of dry manure cleaning technique, solid-liquid separation for manure management, anaerobic biogas production for liquid waste and aerobic composting for solid waste, higher application frequency of manure in light of local conditions, and shorter storage time of liquid manure. These measures could contribute to both the recycling of animal waste and the reduction of GHG emissions[15].

3.2.1 Solid-liquid manure separation

Solid-liquid separation of manure is recognized as an effective emission reduction technology. This process can reduce the content of organic matter in the liquid effluent, which can be applied in farmland after storage or treatment, and enable aerobic composting for solid manure for fertilizer. Dinuccio et al.[16] compared GHG emissions of mechanically separated and untreated slurries, and found that GHG emissions of mechanically separated slurry was 30% lower than that of untreated slurry. Gioelli et al.[17] compared GHG emissions from the liquids mechanically separated with that non-mechanically separated, and found that the former was 85 kg CO_2 eq per cubic meters liquid, and the latter 205 kg CO_2 eq under the same conditions. The proportion of greenhouse gas emission reduction was nearly 60%.

3.2.2 Emission reduction through manure storage

Wang et al.[18] quantitatively studied CH_4 and N_2O mitigation potential during the storage of animal farm slurry using the meta-analysis method. The study systematically evaluated the mitigation effects of main technologies on slurry storage, such as mulching, cooling and acidification. They found that CH_4 mitigation potential of slurry storage could reach 9% to 88%, while N_2O emissions could sharply reduced by more than 80% with suitable emission reduction technology. Give methanogens are very sensitive to temperature, lower storage temperature has a reducing impact on CH_4 emissions. Slurry stored in cooler temperature may release 15% to 93% less of CH_4 emissions, and removing slurry from within the production facility to reduce its temperature may lower CH_4

emissions 23% to 46%[19]. Wang et al.[20] compared CH_4 and N_2O emission characteristics of slurry stored at temperatures from 5 to 25 °C, and found that less CH_4 was produced when the temperature was below 15 °C. Also, slurry acidification has been shown to reduce not only ammonia emissions, but also CH_4 emissions. Total GHG (include CH_4 and N_2O) emissions were reduced by 31% to 92% by acidifying raw swine slurry[21]. When the slurry was acidified to pH 5.5–6.0, the indigenous methanogen activity was strongly inhibited.

3.2.3 Greenhouse gas emission reduction by aerobic composting

Use of some additives can reduce CH_4 and N_2O emissions during composting. With meta-analysis, Wang et al.[18] found that CH_4 emissions can be reduced by 16% and N_2O by 32% in composting using additives. Common additives include modified red mud, perphosphate, modified magnesium olivine, biochar and microbial additives. The effects of additives vary between targets and operating environments. Adding phosphogypsum releases SO_4^{2-} ions, which are toxic to methanogens and result in a decrease in CH_4 production[22]. Biochar addition can mitigate CH_4 emissions of compost by 78% to 84%[23] and can also increase the porosity of the compost and facilitate better ventilation for CH_4 mitigation[24]. Adding magnesium salt and phosphoric acid to composting in manure to form struvite crystallization can reduce nitrogen loss and N_2O emissions by 9% to 80%[25].

4 MITIGATION STRATEGIES TO REDUCE GREENHOUSE GAS EMISSIONS FROM THE LIVESTOCK PRODUCTION IN CHINA

4.1 Improving animal productivity and optimizing dietary patterns

While ensuring animal production and quality of the products, efficiency of animal production can be improved through selection, cultivation, reproduction and promotion of new breeds of high-yield and low-emission livestock and poultry. In addition, to reach the maximize benefits of improved feed quality, reductions in animal numbers need to be part of the strategy[5] to reduce GHG emission intensity per unit of animal product. Based on national statistical yearbooks and inventory data, this paper compares and analyzes GHG emission intensities from major animal products at the production stage from 2005 to 2014. The results show that emission intensities from beef, milk and poultry products (meat and eggs) follow a gradual descendent trend; emission intensity of pork remains generally stable while that of mutton shows a slow rise. Animal products from the highest to the lowest emission intensities at the production stage are mutton, beef, pork, milk and poultry products (meat and eggs), among which emissions of mutton and beef are significantly higher than those of other products, ranging between 12 and 33 times (Fig. 3). While warranting consumer demand for life quality and protein, outputs of GHG could be mitigated by improving animal productivity and reducing farming scale or shortening breeding cycles. Meanwhile, optimizing dietary pattern of foods of animal origin and increasing proportions of milk and poultry meat can also help reduce GHG emissions. From a healthy diet perspective, “white meat” is healthier than “red meat”. According to World Health Organization, provided that the protein nutritional quality of duck and goose meat is similar to that of pork, chicken, beef and mutton, duck meat contains 65% of unsaturated fatty acids, two times higher than that of beef and mutton and one and half times higher than that of pork[26].

4.2 Optimizing feed nutrients formula and improving feed efficiency

Changing concentrate-to-forage ratio (CTFR) in the ration of ruminants, improving the quality of forage, and promoting whole-plant maize silage can effectively improve feed digestibility for dairy cows and reduce emissions of CH_4 from enteric fermentation. Previous reviews indicate that maize silage as the forage source at CTFR of 4:6 can reduce enteric CH_4 emissions by more than 20%, compared with dry maize stalks[11]. The conversion rate for enteric fermentation CH_4 can decrease from 6.5% to 6% and even lower. In recent years,

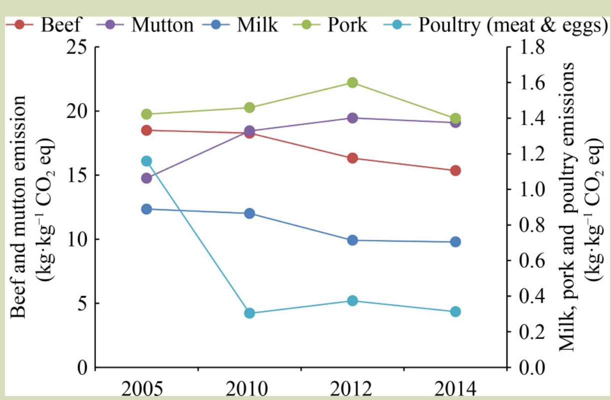

Fig. 3 Evolution in greenhouse gas emission intensities from major livestock and poultry products.

China has continuously advanced supply-side structural reform in the agricultural sector, adjusted the structure of grain crops, cash crops and feed crops, improved the mix of crop varieties though integrating animal husbandry with feed cropping, and expanded plantings of feed crops such as silage maize, alfalfa, oats, sweet sorghum and beans. The Central No. 1 Document in 2019 specified requirements for making appropriate adjustments to the structure of grain crops, commercial crops and feed crops and promoting the production of silage maize, alfalfa and other high-quality fodder crops. Since 2015, the Ministry of Agriculture and Rural Affairs (MARA) has piloted the Grain-to-Feed initiative. As a result, fodder acreage in the first year of the initiative reached 1910 km^2 and 9.95 Mt of high-quality fodder has been produced and stocked. By 2018, the area has exceeded 8670 km^2 for two consecutive years, giving an annual production increase of 65 Mt, an amount that can feed 6 million lactating cows. Whole-plant maize silage can markedly reduce enteric CH_4 emissions from dairy cows while concurrently increasing milk yield.

4.3 Continuously expanding the recycling of animal manure

Manure management is one of the main sources of GHG emissions from the livestock industries. With the rapid expansion of animal farming, waste management methods in China have also undergone major changes. At present, manure treatment focuses on storage and composting of solid waste and liquid storage. In recent years, MARA, the Ministry of Finance, and the National Development and Reform Commission have increased support for the recycling of animal waste, and implemented the recycling scheme of animal waste at the county level and projects for non-point source pollution control in key river basins and biological fertilizer use in both crop and animal production. These efforts have significantly widen the available recycling methods for animal waste. By 2021, about 76% of animal waste across China was comprehensively reused and 97% of large-scale animal farms were equipped with waste recycling equipment. As actions on the recycling of animal waste continue to broaden, an increasing proportion of animal waste is ready for use, thereby effectively reducing GHG emissions during manure management process.

5 CONCLUSIONS

As China strives to achieve carbon peak and carbon neutrality, the livestock sector is experiencing a difficult period balancing efficient production with green, low-carbon and coordinated development. Therefore, it is imperative to explore greener, safer and low-carbon methods of animal farming, so as to address the contradiction between human food needs and ecological environment. At present, research on GHG mitigation in China remains in the initiation phase, focusing on animal productivity and manure recycling, and GHG emission mitigation. Given the overall requirement of green, low-carbon and high-quality development of agriculture, and ensuring food security as well, greater effort should be made to build synergies between pollution control and carbon reduction, technical research and development, and the uptake of whole-chain technologies. To coordinate climate change efforts, and advance emission reduction and carbon sequestration in animal husbandry, GHG mitigation must be a key to the entire process covering the whole process of animal husbandry production management. Investment in research and innovation should be strengthened to provide more policy support and nurture more professionals, finally to deliver on green and low-carbon development of the livestock industries.

In the future, China's low-carbon endeavor in the livestock sector should center on the following three aspects: (1) strengthening the basic research on pollution control and carbon reduction in the entire process of animal husbandry and innovative studies on application technologies, and pursuing green, low-carbon and efficient development of livestock industries; (2) enhancing monitoring and assessment by applying modern information technology in an integrated manner, monitoring GHG emissions throughout the entire process, and conducting science-based assessment of GHG emissions and emission reduction potential at each step; and (3) building standardized systems for emission reduction and carbon sequestration in the livestock sector, developing methodologies and technical standards for the monitoring, accounting, assessment and verification of GHG emission reduction, and setting up a reportable, measurable and verifiable technical system.

Acknowledgements

This study was sponsored by the National Key R&D Program of China (2022YFE0115600), Agricultural Science and Technology Innovation Program (CAAS-ZDRW202110), and China Agricultural Research System (CARS-42-23). We are also grateful to the anonymous reviewers for their constructive comments on this article.

Compliance with ethics guidelines

Zhiping Zhu, Yue Wang, Ting Yan, Zherui Zhang, Shunli Wang, and Hongmin Dong declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

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