Journal of Cleaner Production 149 (2017) 653–664

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

# Comparison of net GHG emissions between separated system and crop-swine integrated system in the North China Plain

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ARTICLE INFO

*Article history:*
Received 24 August 2016
Received in revised form
5 December 2016
Accepted 14 February 2017
Available online 17 February 2017

*Keywords:*
Net GHG emissions
Crop production system
Swine production system
Crop-swine integrated system
Agricultural wastes

ABSTRACT

Agriculture causes 10–12% of global GHG ($CO_2$, $CH_4$ and $N_2O$) emissions. GHG emissions from Chinese agriculture have been estimated at 819.97 Mt $CO_2$-equivalence ($CO_2$-eq); among them, total annual GHG emissions from the production of grain and livestock have been estimated at 374 Mt $CO_2$-eq and 445 Mt $CO_2$-eq, respectively. Because of food demand, food production has intensified, resulting in the separation of crop production and livestock rearing. This separation has increased the application of outside resources and agricultural waste, aggravating GHG emissions and other ecological and environmental problems. This research attempts to mitigate GHG emissions by improving soil carbon sequestration of crop production and decreasing emissions from swine-rearing waste. Net GHG emissions (NGHGE) between an integrated system and a separated system are compared in this study from a life-cycle perspective. The causes of different GHG emissions between these two systems are analyzed and mitigation strategies are proposed. The results show that the NGHGE of crop-swine integrated and separated systems were 24,917.95 kg $CO_2$-eq/ha/yr and 27,732.70 kg $CO_2$-eq/ha/yr, respectively, for 215 head of pigs. The integrated system reduced GHG by 1381.33 kg $CO_2$-eq/yr mainly due to the recycling and reuse of pig manure in croplands. Meanwhile, the integrated system increased soil carbon storage by 35.92% compared with the separated system, although it increased soil $CH_4$ and $N_2O$ emissions. In conclusion, these results indicate that through a series of methods, such as recycling agricultural waste, the integrated system can reduce net GHG emissions by 10.15% compared with separated systems. Although much work remains to adopt the integrated system to reduce GHG emissions, the crop-swine integrated system should be given priority to mitigate anthropogenic net GHG emissions.



## 1. Introduction

Currently, the increasing number of greenhouse gases (GHG) emitted to the atmosphere is among the most serious environmental problems. Agricultural systems, both crop production and pig rearing, are emission sources and sinks of GHG, including carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$). Agriculture is a source of three primary GHGs that are responsible for 10–12% of the global estimated GHG emissions, 50% of $CH_4$ and 60% of $N_2O$ (IPCC, 2007). If no agricultural policies are added, agricultural emissions of $CH_4$ and $N_2O$ in 2030 will increase by 60% and 35%–60%, respectively, compared their reported levels from 2005 (IPCC, 2007). In China, GHG emissions from agriculture amounted to 819.97 million tons $CO_2$-equivalence ($CO_2$-eq) (NDRC, 2012), resulting in 21.18% of global GHG emissions (Wang et al., 2014). GHG emissions also came from the processing of agricultural products, such as supplementary inputs by human beings (Dubey and Lal, 2009). Conversely, through photosynthesis, a crop-production system immobilizes atmospheric carbon dioxide to carbohydrates and then provides food for animal and human survival. Simultaneously, through soil carbon storage (Lal, 2015), agriculture has a large potential to reduce GHG emissions.

Traditionally, for more than 2000 years, farmers in China have relied on the recycling of organic materials to preventing decreases

*Abbreviations:* GHG, greenhouse gas; NGHGE, net GHG emission; GWP, global warming potential; CSIS, Crop-swine integrated system; CPS, Crop production system; SPS, Swine production system.

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http://dx.doi.org/10.1016/j.jclepro.2017.02.113
0959-6526/

in soil fertility. However, with the specialization and intensification of agriculture, both crop production and livestock rearing rely on outside supplies of materials and energy, resulting in the decoupling of animal and plant production in China (Ju et al., 2005). GHG emissions caused by this separation are becoming increasingly serious. First, separation causes a great deal of agricultural waste. Agricultural wastes, such as crop residue and livestock feces, are now growing rapidly as agricultural production increases. Among a variety of GHG emission sources in agriculture, organic waste generated by agricultural management practices not only contaminates the environment but also causes GHG emissions. Globally, a substantial quantity of organic waste, such as plant residues ($3.8 \times 10^9$ Mg/yr) and animal manure ($7 \times 10^9$ Mg/yr), are produced (Lal, 2005; Ramya et al., 2013). Emissions of these large amounts of waste are not negligible; for example, residue emissions from maize production accounted for 58.4% of the total crop emissions in China (Ramya et al., 2013). In addition, the more frequent use of relatively cheap inorganic fertilizers and of machinery for farming tillage and irrigation has increased the use of fossil fuels and aggravated GHG emissions. Combining crop production with animal husbandry to reduce agricultural waste and GHG emissions may be effective. Thus, a complete accounting of net GHG emissions (NGHGE) in both cropping and livestock systems is of great importance.

Currently, many studies are investigating the ecological problems of combining crop production with animal husbandry (Zhang et al., 2007; Wu et al., 2014; Wei et al., 2009). The life-cycle perspective involves the systematic collection and interpretation of material flow in all relevant processes of a product and is widely employed for farm-level NGHGE. In general, the life-cycle perspective involves assessing the total NGHGE of a system at each step during the creation of a product. A complete analysis of the impact of a system would consider all stages, from “cradle to farm-gate.” Recent studies, such as Nan et al. (2015); Riaño and García-González (2015), have reported that the carbon footprint of winter wheat and summer maize in the North China Plain were 1.36 kg $CO_2$-eq/kg and that conventionally stored anaerobic swine manure had emissions of 1204 t $CO_2$-eq/year. Apart from the life-cycle perspective, the ecological input–output method has been widely applied to evaluate GHG emissions (Chen and Chen, 2010; Zhang and Chen, 2014). Agriculture can calculate embodied GHG emissions based on an ecological input–output analysis of environmental emissions and resource use (Chen et al., 2010). Technologies have also been developed to reduce agricultural GHG emissions. These technologies have often focused on reducing a single compound or have concentrated on a single management stage (Decock, 2014; Gao et al., 2014). As a result, targeted emissions have been reduced, but others have increased. Studies of the overall GHG emissions of different system management alternatives are indispensable. Currently, two types of methods, crop-based and soil-based approaches, are mainly used to estimate the NGHGE of agriculture (Huang et al., 2013). The crop-based approach is typically estimated from net biome productivity (NBP), combining soil $N_2O$ emissions and indirect GHG emissions from agricultural input. However, this approach is controversial because some researchers have argued that $CO_2$ photosynthesized by crops is returned to the atmosphere as respired $CO_2$; thus, they believe that annual net $CO_2$ emissions and carbon sequestrations should be assumed to be zero. We suggested that the soil-based approach should be used to assess the NGHGE of agricultural systems because soil carbon storage is a long-lived carbon pool and provides more reliable results. As an effective strategy, an estimation of the NGHGE of crop production using the soil-based approach was adopted.

Based on the above studies, this paper used a case study method of crop production and swine rearing in the North China Plain to explore NGHGE. The different systems are defined by GHG emissions associated with both crop and swine production from “cradle to farm-gate,” originating from the life-cycle perspective. The objectives of this study were to (1) quantify NGHGE from integrated and separated systems, (the integrated system refers to the crop-swine integrated system (CSIS); the separated system includes both the crop production system (CPS) and the swine production system (SPS)); (2) compare the integrated and separated systems and discuss the NGHGE of different agricultural circulation systems; and (3) suggest mitigation strategies for GHG emissions.

## 2. Materials and methods

### 2.1. Definition of goal, functional unit and allocation

In this paper, NGHGE of the crop-swine integrated system was calculated, analyzed and compared with that of separated systems (the separated crop production system and separated swine production system). A life-cycle perspective was used to provide an objective framework for estimating and evaluating emission management scenarios with respect to $CO_2$-equivalents ($CO_2$-eq). The results are expressed in kilogram $CO_2$-equivalent per hectare per year for a certain number of pigs (kg $CO_2$-eq/ha/yr for pigs), kilogram $CO_2$-equivalent per hectare per year (kg $CO_2$-eq/ha/yr) and kilogram $CO_2$-equivalent per year for a certain number of pigs (kg $CO_2$-eq/yr for pigs) for the CSIS, CPS and SPS, respectively.

### 2.2. Characteristics of the systems

#### 2.2.1. System boundaries

This study provides a full chain analysis of the GHG emission implications for the separated and crop-swine integrated systems in the North China Plain. On-farm and off-farm fluxes related to crop production, livestock rearing, and forage processing; the fluxes from the production of mineral fertilizers, pesticides, and energy; and emissions from agricultural waste treatments were considered. It should be noted that the definition of the crop-swine integrated system aligns with the sum of the separated crop production and separated swine production systems. GHG emissions associated with these materials and energy resources in this study were calculated according to equation:

$$GWP_{crop\text{-}CPS} = \sum In^{*}EF \tag{1}$$

where $GWP_{crop\text{-}CPS}$ includes emissions associated with the materials and energy resources. The resources included farm operations, such as electricity for irrigation and machinery for tillage, and agrochemical inputs, such as chemical fertilizers and fossil fuels. Also considered were investments, such as pesticides, seeds, irrigation and labor, according to the actual agricultural management. The amount of each item of input and its emission factor for the GHG cost are In and EF, respectively. The emission factors refer to Chinese studies since they use local data that is closer China’s reality. The agricultural inputs of crop production and swine rearing as well as the emission factors are presented in Table 1 and Table 2, respectively.

GHG emissions from agricultural waste treatments included $CH_4$ and $N_2O$ emissions during manure management with respect to housing, storage and spreading. GHG emissions of urine and feces were based on 2006 IPCC guidelines (IPCC, 2006). Livestock waste was discarded casually in the SPS throughout the year, so when we calculated the $CH_4$ emissions, the methane conversion factors (MCF) in the SPS were considered to be 2% for winter, 5% for