Sci. Bull. (2015) 60(6):598–606
DOI 10.1007/s11434-014-0679-6

www.scibull.com
www.springer.com/scp

Mitigating greenhouse gas emissions through replacement of chemical fertilizer with organic manure in a temperate farmland

Haitao Liu · Jing Li · Xiao Li · Yanhai Zheng · Sufei Feng · Gaoming Jiang

Received: 17 February 2014 / Accepted: 23 August 2014 / Published online: 7 January 2015

Abstract Burning crop residues and excessive use of chemical fertilizers results in an enormous waste of biological resources, which further weakens the potential capacity of the agro-ecosystem as a carbon sink. To explore the potential of farmlands acting as a carbon sink without yield losses, we conducted an experiment on a temperate eco-farm in eastern rural China. Crop residues were applied to cattle feed, and the composted cattle manure was returned to cropland with a winter wheat and maize rotation. Four different proportions of fertilizers were designed: 100 % cattle manure, 100 % mineral nitrogen, 75 % cattle manure plus 25 % mineral nitrogen, and 50 % cattle manure plus 50 % mineral nitrogen. Crop yield and greenhouse gas (GHG) emissions were carefully calculated according to the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories 2006. Our results showed that replacing chemical fertilizer with organic manure significantly decreased the emission of GHGs. Yields of wheat and corn also increased as the soil fertility was improved by the application of cattle manure. Totally replacing chemical fertilizer with organic manure decreased GHG emissions, which reversed the agriculture ecosystem from a carbon source (+2.7 t CO_2-eq. hm^{-2} $year^{-1}$) to a carbon sink (−8.8 t CO_2-eq. hm^{-2} $year^{-1}$). Our findings provide useful insights for improving agricultural ecosystems under global change scenarios.

Keywords Crop residue · Chemical fertilizer · Cattle manure · Crop yield · Greenhouse gas emissions · Climate change

1 Introduction

Approximately one-third of global greenhouse gases (GHGs) come from agriculture. These emissions include direct energy use, the production of fertilizers and pesticides, indirect emissions from livestock, use of machinery and equipment, as well as soil degradation and land-use change [1]. Total GHG emissions from agriculture are expected to reach 8.3 Gt CO_2 equivalents per year by 2030, compared to the current level of approximately 6 Gt CO_2 equivalents annually [2]. To mitigate GHG emissions and retain soil fertility, organic agriculture might be a wise choice for decreasing the intensive use of synthetic fertilizers, protecting environments, and further improving crop yields [1, 3].

Lessening GHG emissions tops the agenda of the world's sustainable development research today. Occupying 11 %

SPECIAL TOPIC: Land-ocean integrated research and development of carbon sink

Haitao Liu, Jing Li, and Xiao Li contributed equally to this work.

Electronic supplementary material The online version of this article (doi:10.1007/s11434-014-0679-6) contains supplementary material, which is available to authorized users.

H. Liu · J. Li · X. Li · Y. Zheng · G. Jiang (✉)
State Key Laboratory of Vegetation and Environmental Change,
Institute of Botany, Chinese Academy of Sciences,
Beijing 100093, China
e-mail: jgm@ibcas.ac.cn

H. Liu
University of the Chinese Academy of Sciences, Beijing 100049,
China

S. Feng
State Key Laboratory of Crop Biology, College of Agronomy,
Shandong Agricultural University, Tai'an 271018, China

of the earth's terrestrial surface, farmland plays important roles in global carbon circulation [4, 5]. Crop residues, if properly utilized, can act as ideal feed and fertilizer as well as bio-energy. However, along with the rapid development of industrialization and urbanization, crop residues are nowadays abandoned or directly burnt in the fields in many regions, especially in the developing countries of the world. Burning of crop residues is one of the most significant GHG emission events in agricultural areas, especially in those economically fast growing countries such as China. According to our estimation, China produces about 630 million tons of crop residues each year, with only 23 % of them being used as livestock forage and the other 77 % abandoned or burned [6]. However, this could be appropriately mitigated through ecological agriculture practices.

A number of investigators have expressed interest in crop residue cycling in rural areas [7–9] and the positive effect of organic manure application on soil quality and crop production [10, 11]. Nevertheless, few scientific studies have been conducted to evaluate the beneficence of biomass resource utilization and the potential reduction of GHG emissions in agro-ecosystems if all factors are fully considered. We hypothesized that farmland could act as a carbon sink rather than a carbon source if fewer fertilizers are used and more organic carbon is sequestered in the soils; the reason being that industrially producing fertilizers and distributing them to croplands can lead to a huge carbon emission.

In the present study, we explored a methodology for optimizing the use of biomass resources and the mitigation of carbon emission in a rural area of eastern China. We applied crop residues to cattle feed, composted the manure, and then applied it to farmland instead of total or part chemical fertilizer, thus avoiding the burning or waste of biomass recourses, which could contribute to GHG emissions. We aimed to answer the following questions: With all or part of the chemical fertilizer input replaced by organic manure, (1) could total GHG emissions of the agro-ecosystem decrease? (2) could soil quality and crop yield be improved? The aim of this study was to explore a more sustainable approach to maximizing carbon sequestration potential without crop yield losses in an eco-farming system.

2 Materials and methods

2.1 Study area

This experiment was conducted at the Eco-farm Research Station of Shandong Agriculture University (35°26′21″N, 117°50′11″E), located in Pingyi County, eastern Shandong Province of China. The climate type is semi-humid continental monsoon, with an average annual temperature of 13.2 °C and annual precipitation of 770.2 mm. Figure 1 shows the precipitation and mean air temperature during the experimental period. The soil type is brown earth. The traditional cropping system is characterized as winter wheat (*Triticum aestivium* L.) and maize (*Zea mays* L.) rotation. Winter wheat grows from October to June of the following year and maize from late June to early October of the same year. Fertilizer is initially applied before sowing and again around the middle of the growth stage for topdressing. The majority of the nutrient input is realized through chemical fertilizer application. Total cropland in the village amounts to 33.3 hm^2, yielding 738.8 tons of fresh crop residues every year with most of them being abandoned or burned [9].

2.2 Organic manure application rates

The research was designed following a full winter wheat–maize rotation. According to our survey, the average nutrient input was 472.5 kg total nitrogen (TN) per hectare per year, being equally divided into two crops. On the premise of applying equivalent TN (236.25 kg per hectare each growing season), four treatments (each 889 m^2) were designed: cattle manure (M), mineral nitrogen (Nm), 75 % cattle manure plus 25 % mineral nitrogen (NmM_1), 50 % cattle manure plus 50 % mineral nitrogen (NmM_2). We chose the widely used urea (nitrogen = 46 %) as the chemical mineral nitrogen source, 60 % of which was applied before sowing and the remaining 40 % as top dressing during each season. The manure applied to the field was collected from cattle of the nearby Hongyi Organic Farm and then composted. The TN content was measured before utilization to determine the dosage (Table 1). Both composted manure and urea were sprinkled evenly on the field and immediately incorporated into the soil prior to sowing. The manure was incorporated 30 cm

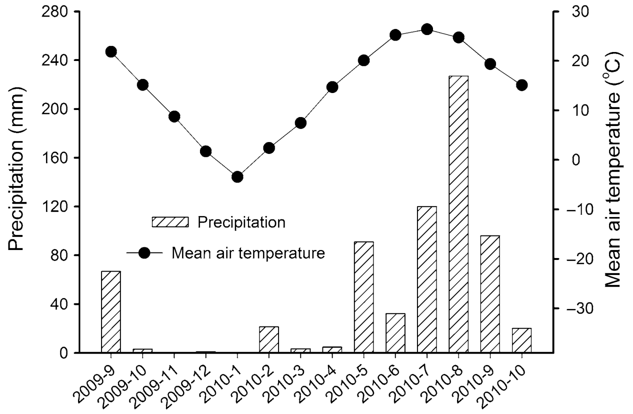

Fig. 1 Precipitation (mm) and mean air temperature (°C) by month and year from 2009-09 to 2010-10

Table 1 Consumption of crop residues for each treatment and the properties of the cattle manure

	M	NmM_1	NmM_2	Nm
Total nitrogen concentration of composted cattle manure (winter wheat) (%)	1.70	1.70	1.70	–
Total nitrogen concentration of composted cattle manure (maize) (%)	1.52	1.52	1.52	–
Water content of composted cattle manure (winter wheat) (%)	70	70	70	–
Water content of composted cattle manure (maize) (%)	62.43	62.43	62.43	–
Total amount of nitrogen resource from cattle manure (kg hm^{-2} $year^{-1}$)	472.5	354.38	236.25	–
Cattle manure consumed (kg hm^{-2} $year^{-1}$)	13,897.05	10,422.79	6,948.53	–
Average amount of nitrogen excrement per cattle per year (kg N)	25.63	25.63	25.63	–
Number of cattle breeding	18.43	13.82	9.22	–
Crop residues consumed (kg)	22,536.20	16,899.10	11,274.22	–
Winter wheat straw yield (kg hm^{-2})	8,628.57	9,824.25	8,605.16	9,004.65
Maize stalk yield (kg hm^{-2})	6,906.76	7,215.37	8,123.90	7,255.39
Crop residues unused (kg hm^{-2})	−7,000.87	140.52	5,454.84	16,260.04

M Treatments: 100 % manure, *NmM_1* 75 % cattle manure + 25 % mineral nitrogen, *NmM_2* 50 % cattle manure + 50 % mineral nitrogen, *Nm* 100 % mineral nitrogen

deep into the soil. In addition, we used traditional methods to manage the crop field during the experimental run. These included irrigating twice during the winter wheat season but not during the maize season, a single weeding of each crop, and plowing before the winter wheat sowing; the depth of the plowing layer was 30 cm.

2.3 Sampling and processing

All field works took place between September 2009 (start of the winter wheat season) and October 2010 (end of the maize season). Soils from all sites were sampled in September and November 2009, and every month from March to October 2010. Soils were randomly sampled from all sites using a 5 cm inside diameter corer. Cores were divided into increments of 0–20 and 20–40 cm. Any litter, loose stones, or plant shoots were removed before sampling. The soil samples were dried in air sieved to <2 mm for the analysis of soil pH [12], soil organic carbon (SOC), and total Kjeldahl nitrogen (TKN) [13]. Soil samples of 50 cm^3 were used to determine soil water content and bulk density [14]. Total nitrogen, phosphorus, and potassium in the composted cattle manure were measured before application. The winter wheat yield was determined through the manual harvesting of four randomly chosen 1 m^2 quadrants per treatment. For corn, four rows of 15 continuous plants were harvested per treatment.

2.4 Estimation of GHG emissions and carbon sequestration potential

The method suggested by the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories 2006 was introduced to estimate GHG emissions over the experimental period [15]. According to the IPCC report, GHGs include dozens of categories of gases with global warming potential; however, in the system, we treated CO_2, CH_4, and N_2O as the key GHGs emitted to the environment [16]. We, therefore, calculated in detail the CO_2, CH_4, and N_2O emissions using the collected data and the IPCC formulas in order to investigate the contribution of the four test scenarios to global warming. According to the IPCC, if the Global Warming Potential (GWP) of CO_2 is 1, CH_4 should be 21 and N_2O should be 310. Following IPCC's good practice, we used Tier 2 and our experimental data to estimate GHG emissions; only CO_2 emissions from urea fertilization were evaluated using Tier 1. If insufficient data were available for the evaluation, we employed suitable default values recommended by the IPCC expert panel. Table S1 shows the main equations used to calculate the GHG emissions, according to the IPCC Guidelines for National Greenhouse Gas Inventories 2006.

The potential capacity of the studied agro-ecosystem was estimated by calculating each energy value, including those for chemical fertilizer production, urea application, cropland management, crop residue biomass, underground biomass, crop residue burning, enteric fermentation of cattle, cattle breathing, manure management, and soil carbon change. Every value was converted to CO_2 equivalence.

2.5 Statistical analyses

All measurements except for GHG emissions were made in quadruplicate and reported as mean values with standard error. The data were analyzed using one-way analysis of variance (ANOVA) and SPSS statistics 17.0 for windows. Differences between treatments were considered significant at $P \leqslant 0.05$. Analyses were performed in Sigma Plot 10.0.

3 Results

3.1 Recycling of crop residues

Combined with the data from cattle breeding, including the dry matter and excrement dry matter of daily forage, we calculated that 22.5, 16.9, 11.3, and 0.0 t hm^{-2} crop residues were consumed in treatments with 100 % manure (M), 75 % cattle manure + 25 % mineral nitrogen (NmM$_1$), 50 % cattle manure + 50 % mineral nitrogen (NmM$_2$), and 100 % mineral nitrogen (Nm), respectively (Table 1). Based on field sampling, we calculated that the M, NmM$_1$, NmM$_2$, and Nm systems produced 15.5, 17.0, 16.7, and 16.2 t hm^{-2} year^{-1} crop residues, respectively. The usage ratios of residues were 145.2 %, 99.4 %, 67.7 %, and 0 %, respectively, for M, NmM$_1$, NmM$_2$, and Nm treatments. The M system not only reused nearly all of its crop residues through cattle breeding, but also consumed about 7 t hm^{-2} gathered crop straw from external sources. NmM$_1$ and NmM$_2$ systems also displayed a positive reuse of straw, with 0.14 t and 5.4 t hm^{-2} remaining, respectively. In contrast, in fields treated with Nm, most of the crop residues were burned according to the common practice in the study area.

3.2 Crop yields

As shown in Fig. 2, there were no significant differences ($P > 0.05$) among the four treatments in winter wheat yield, with the grain yield being 6.1, 6.9, 6.1, and 6.4 t hm^{-2}, respectively, for M, NmM$_1$, NmM$_2$, and Nm. Even the M treatment, which obtained all its nutrition from organic manure, had a winter wheat grain yield equivalent to the others. In contrast, the yields of maize were 6.8, 7.1, 8.0, and 7.2 t hm^{-2}, respectively, with M, NmM$_1$, NmM$_2$, and Nm. With respect to total yield (wheat + maize), there were significant differences between NmM$_1$, NmM$_2$, and M in grain yields, with the relative order being NmM$_2$ (14.2 t hm^{-2}) > NmM$_1$ (14.1 t hm^{-2}) > Nm (13.5 t hm^{-2}) > M (12.9 t hm^{-2}) ($P < 0.05$). However, there was no significant difference between M and Nm.

Similarly, the straw yields from winter wheat showed no significant differences among the four treatments, with fields treated with M, NmM$_1$, NmM$_2$, and Nm yielding 8.6, 9.3, 8.3, and 9.9 t hm^{-2}, respectively. However, the stalk yields from maize amounted to 6.5, 9.0, 7.6, and 6.9 t hm^{-2}, respectively, for fields treated with M, NmM$_1$, NmM$_2$, and Nm ($P < 0.01$).

3.3 Annual SOC and TN

SOC was significantly correlated with soil TN concentration at different soil depths (Fig. 3). As expected, at a depth of 0–20 cm, SOC content following organic manure application was much higher than that after the chemical fertilizer treatment. At a depth of 20–40 cm, however, it initially showed an increasing trend after fertilizer application, then decreased after several months, and finally displayed no significant difference in the SOC and soil TN content among treatments. All four treatments showed a slight increase after a year of crop rotation, especially in the first five months.

3.4 GHG emissions

To understand the impact of fertilizer alternatives on global climate change, we employed IPCC methods to measure

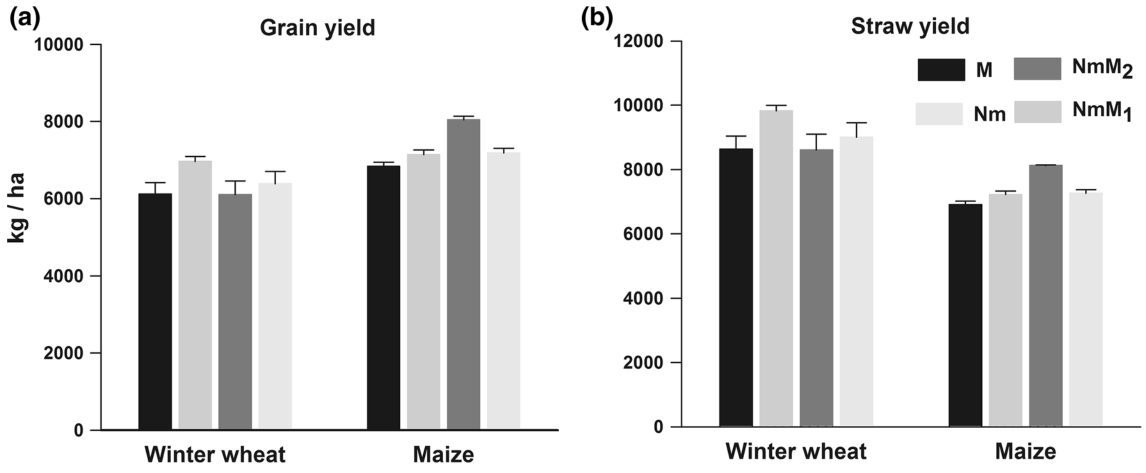

Fig. 2 Evaluation of crop yields (**a**) and straw yields (**b**) before harvest

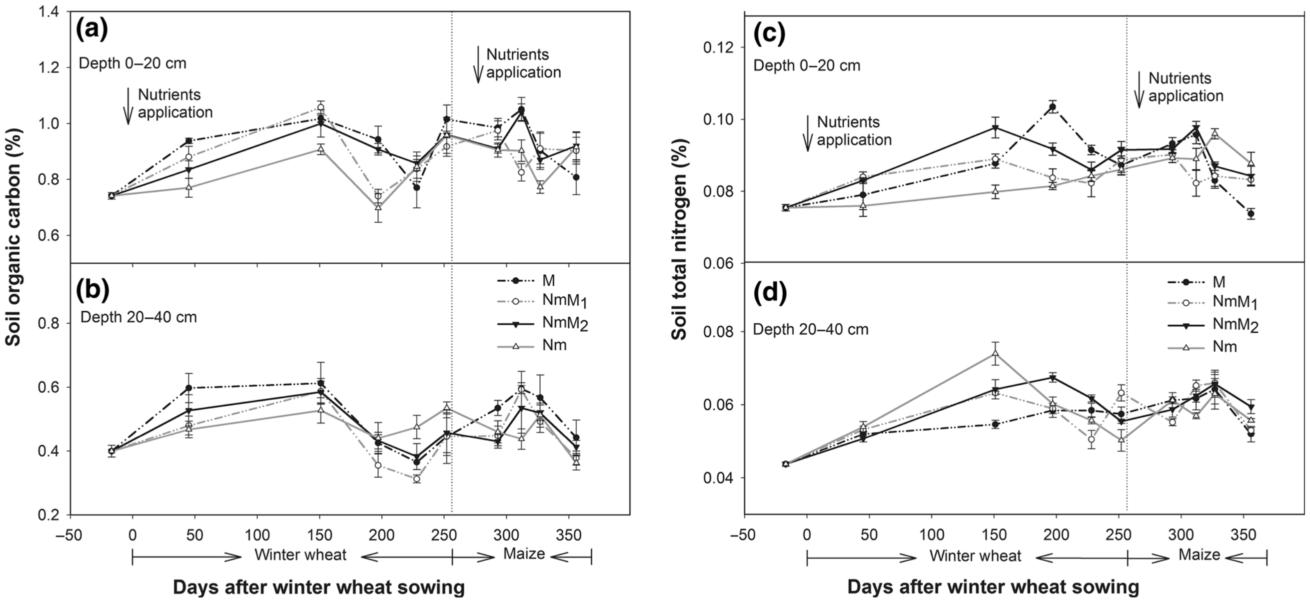

Fig. 3 Dynamic changes of soil carbon (**a**, **b**) and soil nitrogen (**c**, **d**) in the two growing seasons of winter wheat and maize, respectively in 0–20 cm soil depth (**a**, **c**) and 20–40 cm soil depth (**b**, **d**). Arrows pointed downwards indicate nutrients application time

GHG gains and losses through all the processes involved in this experiment (Table 2). According to the warming potential, we translated all emitting values to CO_2 equivalent (CO_2-eq.) in estimating the contribution of the four fertilizer treatments to the environmental state.

Owing to the high warming potential and abundance of cattle worldwide, CH_4 emission levels through enteric fermentation were calculated as one of the focal points of our estimation. Through cattle enteric fermentation, M, NmM_1, NmM_2, and Nm emitted 676.1, 507.0, 338.2, and 0.0 kg hm^{-2} $year^{-1}$ CH_4, equaling 14.197, 10.646, 7.102, and 0 kg CO_2-eq. hm^{-2} $year^{-1}$, respectively. Cattle respiration also plays an important role in CO_2 emissions. Excluding the carbon excreted by cattle, carbon emissions caused by cattle respiration and body growth amounted to 15.2, 11.4, and 7.6 t CO_2-eq. hm^{-2} $year^{-1}$ for M, NmM_1, and NmM_2, respectively.

Organic manure application could also give rise to soil N_2O and CH_4 emissions. The warming potential of N_2O is much higher than that of CO_2, which also wields a significant impact on global warming. In this study, M-treated fields released 11.0 kg hm^{-2} N_2O and 20.7 kg hm^{-2} CH_4 over the entire year, followed by NmM_1 and NmM_2. Nevertheless, with the application of 472.5 kg N hm^{-2} $year^{-1}$ urea, Nm-treated fields showed a net emission of 2.7 t CO_2-eq.$^{-1}$ hm^{-2} $year^{-1}$, ranking number one in GHG emissions. In contrast, M-treated fields sequestered 8.8 t CO_2-eq. hm^{-2} $year^{-1}$ over the entire year according to our calculation, followed by NmM_1 and NmM_2 treatments, with 7.1 and 3.9 t CO_2-eq. hm^{-2} $year^{-1}$ being sequestered.

4 Discussion

4.1 Recycling of crop stalks

From the points of view of sustainable agriculture and GHG mitigation, a rational approach toward recycling the great sum of crop residues is a key issue in rural areas worldwide. Nowadays, crop residues are mainly used to create biogas, briquette, bio-diesel, and heat as traditional firewood [17]. However, all these approaches ignore the potential contribution of photosynthetic products to GHG emissions. Historically, crop stalks have been popularly utilized as forage and composted manure, however, since the First Green Revolution, chemical fertilizers have gradually replaced organic manure, leading to the abandonment of crop residues. In our experiments, cropland fertilized with organic 100 % cattle manure (M) produced 15.5 t hm^{-2} $year^{-1}$ of wheat straw and corn stalk. However, cattle consumption was 22.5 t hm^{-2} $year^{-1}$, which necessitated the use of crop residues from both inside and outside of the crop system to meet feed requirements. Although part of the carbon held in crop residues is later emitted to the atmosphere through cattle respiration, the remainder is excreted and returned to the soil to enhance the carbon storage of croplands. Appling 75 % or 50 % cattle compost, as with the NmM_1 and NmM_2 systems, still consumed 16.9 kg and 11.2 t hm^{-2} $year^{-1}$ crop residue, with only 0.14 and 5.4 t hm^{-2} $year^{-1}$ wasted, respectively. In contrast, with none cattle raised when 0 % organic manure was used (Nm), it was noted that as large as

Table 2 Three main categories of greenhouse gas (CO_2, CH_4, N_2O) emission inventories of the studied agro-ecosystem

Emission inventory lists	CO_2 (kg hm^{-2})				N_2O (kg hm^{-2})				CH_4 (kg hm^{-2})			
	M	NmM_1	NmM_2	Nm	M	NmM_1	NmM_2	Nm	M	NmM_1	NmM_2	Nm
Chemical fertilizer production (−)	0.00	−2,417.90	−4,835.79	−9,671.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urea application (−)	0.00	−137.50	−275.00	−550.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cropland management (−)	0.00	0.00	0.00	0.00	−10.75	−9.00	−9.25	−11.20	0.00	0.00	0.00	0.00
Crop residue (+)	24,638.86	27,047.54	26,488.51	25,786.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Underground biomass (+)	9,642.51	10,576.00	10,383.80	10,085.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crop residue burning (−)	11,103.30	−182.10	−7,068.93	−21,071.40	0.00	−0.08	−3.25	−9.70	0.00	−0.32	12.61	−37.60
Enteric fermentation of cattle (−)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	−676.07	−506.96	−338.22	0.00
Cattle breathing (−)	−15,208.99	−11,404.68	−7,608.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manure management (−)	0.00	0.00	0.00	0.00	−11.04	−8.28	−5.52	0.00	−20.70	−15.52	−10.35	0.00
Soil carbon change (+)	0.9	2.35	3.16	2.87	–	–	–	–	–	–	–	–
Total CO_2 equivalence (kg hm^{-2})[a]	30,176.58	23,483.72	17,087.13	4,582.26	−6,755.10	−5,382.49	−5,589.50	−6,478.70	−14,632.12	−10,978.93	−7,584.92	−789.60
Carbon sequestration (kg CO_2-eq.)	8,789.57	7,122.4	3,912.71	−2,686.03	–	–	–	–	–	–	–	–

The calculations are based on the *Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories 2006*

(−) denotes emission, (+) denotes sequestration

[a] According to IPCC, if Global Warming Potential (GWP) of CO_2 is 1, CH_4 should be 21 and N_2O should be 310. A GWP compares the radiative forcing of a ton of a greenhouse gas over a given time period (e.g., 100 years) to a ton of CO_2

16 t hm^{-2} $year^{-1}$ crop stalks were burnt by farmers in the field. Therefore, cattle breeding can efficiently recycle crop residues, and reduce environmental pollution and carbon emissions. Given the booming and long history of the small-scale peasant economy in China and the abundant human resources in rural areas, cattle breeding is recommended as a superior choice in rural areas to make full use of crop residues.

4.2 Maintaining crop yield

Crop yield is the ultimate goal of agriculture. Seufert et al. [18] reviewed that organic agriculture generally gives lower crop yields than conventional agriculture (average 25 % lower). So people take lower organic agriculture for granted, leading to the blame that organic agriculture does not mitigate GHG emissions [19]. However, a lower yield is not the case for all organic agriculture crops in all climate zones [20]. We have achieved a relatively higher yield with a winter wheat and maize rotation (Fig. 2). The high productivity in this study might be enhanced by many indirect measures based on improving soil fertility and stimulating the roles of plants and microbes in the natural soil processes.

4.3 GHGs emissions

As we can see from Table 2, crop residue burning contributes significantly to CO_2 emissions. If not burned, crop residues and underground biomass serve as the biggest source of CO_2 sequestration in the agro-ecosystem. To fill the forage gap, which could produce enough excrement for use, M treatment did not require the burning of any crop residues; otherwise, it consumed 7.0 t stalks from outside of the system, fixing 11.1 t CO_2 hm^{-2} $year^{-1}$ compared to NmM_1, NmM_2, and Nm which released 0.18, 7.1 and 21.1 t CO_2 hm^{-2} $year^{-1}$, respectively, by burning crop residues alone. Underground biomass (UB) is considered to play a pivotal role in carbon sequestration in soils. We chose to calculate the UB using the default value given by the IPCC. Because the management practices for UB were the same for all four treatments, the sequestration of carbon did not show a significant difference.

CO_2 emissions are contributed to by crop residue burning, microbial decay, and soil organic matter decomposition [21]. To retain the agro-ecosystem integrity, we must also consider the release of CO_2 from chemical fertilizer production, distribution, and application. Because of the output to the outside market, winter wheat and maize grain is the only part we chose to look at for all four scenarios (Fig. 4). Urea production is divided into two processes: ammonia synthesis and urea production. Ammonia production requires a source of nitrogen and hydrogen. Nitrogen is obtained from the air, while hydrogen is separated from natural gas or fossil fuels, such as coal and oil [22]. Alvarez [23] showed that when soil fertility is deficient, adding even chemical fertilizer (CF) could promote soil carbon gains. Nevertheless, some argued that CO_2 emissions from CF production and N_2O from soil could offset the benefits of CF application [24–26]. Carbon, eliminated from the production process and an energy requirement from natural gas or fossil fuels, releases the main potential of CO_2 sequestration here. Urea production utilizes the by-product CO_2 stream from the ammonia synthesis process, which can make a somehow carbon sequestration. However, CO_2 fixed in such a process would be lost through adding urea fertilization to soils. In the presence of water and enzymes, urea ($CO(NH_2)_2$) is converted into ammonium (NH_4^+), a hydroxyl ion (OH–), and bicarbonate (HCO_3–) [15]. In Table 2, we can see that the emission of CO_2 decreased significantly with reductions of urea.

Cattle breeding can lead to increased GHGs especially CH_4. In our study, cattle enteric fermentation, cattle respiration, and manure composting contributed the major part of GHG emissions. Therefore, not only the CO_2 but also the CH_4 and N_2O emissions must be considered in this part. The Food and Agriculture Organization of the United Nations (FAO) estimated that at least 18 % of the world's GHGs come from agriculture, being as large as 7,100 Tg CO_2-eq. $year^{-1}$ [27]. Among this, ruminant animals are the main producers of GHG emissions that are directly or indirectly related to livestock. Ruminant animals produce large amounts of GHGs from the fermentation process, while excrement disposal is also an important carbon source. However, following the estimations of the FAO and the USA, the State of California made an assessment [28] based on the method of the IPCC and found that only 5.4 % of GHG emissions might be associated with agriculture, with merely 2.8 % of them associated with livestock. In our estimation, cattle breeding-related emissions amount to 33.3, 24.9, 16.6, and 0.0 t CO_2-eq. $year^{-1}$, respectively, for M, NmM_1, NmM_2, and Nm.

Although emissions related to cattle breeding were a large burden to the organic manure applied treatments, crop residue recycling and chemical reduction ultimately mean that organic manure systems sequester more carbon. As presented in Table 2, the total sequestrations of CO_2 were 8.7, 7.1, and 3.9 t CO_2-eq. $year^{-1}$, for treatments with M, NmM_1, and NmM_2 respectively. In contrast, 2.6 t CO_2-eq. $year^{-1}$ was emitted from the treatment with Nm. Although emission from cattle enteric fermentation depleted some carbon sequestration ability, the treatments with M, NmM_1, and NmM_2 still demonstrated high carbon

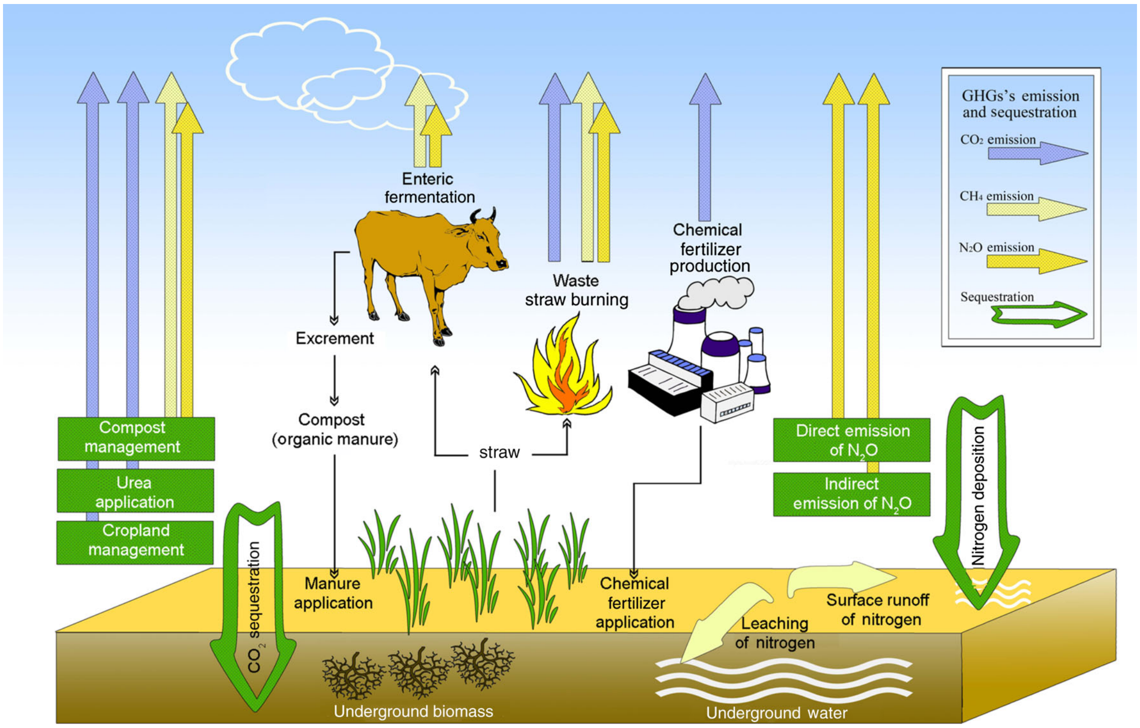

Fig. 4 (Color online) Processes of greenhouse gases emission and sequestration in the studied agro-ecosystem. Arrows pointed upwards indicate emissions of greenhouse gases to the atmosphere, and arrows pointed downwards indicate greenhouse gases sequestration to the agro-ecosystem

pool potentials when sufficient organic manure was applied.

GHG emissions caused by land-use change also attract close attention. Cederberg et al. [29] estimated that, over the past 20 years, beef produced on newly deforested land has released more than 700 kg CO_2-eq. per kg carcass weight under the condition of direct land-use. However, in east China, this consideration does not exist. Unlike clearing forests to build facilities for cattle, Chinese peasants enclose part of the current arable land as cattle depots, which essentially do not cause land-use pattern changes.

5 Conclusions

Making full use of crop residues as forage for cattle, collecting and composting cattle manure, and replacing part of the chemical fertilizer input with organic manure have been successfully shown to be ideal choices to reduce energy waste and cut GHG emissions without crop yield losses. A combination of organic manure and chemical fertilizer demonstrated the best result in improving soil quality and crop yields, while decreasing GHG emissions. Solely utilizing chemical fertilizer on the farmland not only led to increased GHG emissions, but also deteriorated the quality of the soil. Therefore, we recommend the government should encourage these simple and efficient practices.

Acknowledgments This work was jointly supported by the Key Strategic Project of the Chinese Academy of Sciences (KSZD-EW-Z-012-2) and the National Science and Technology Support Program (2012BAD14B00). We acknowledge Dr. Caihong Li and Dr. Yong Li of Institute of Botany, Chinese Academy of Sciences for their advices and help in the statistical analysis. Special thanks go to the staff of the Eco-farm Research Station of Shandong Agricultural University for providing living facilities during the experimental run.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. FAO (2011) Organic farming and climate change mitigation. A report of the Round Table on Organic Agriculture and Climate Change. Rome, Italy
2. Smith P, Martino D, Cai Z et al (2007) Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
3. Niggli U, Fließbach A, Hepperly P et al (2009) Low greenhouse gas agriculture: mitigation and adaptation potential of sustainable farming systems. Ökologie Landbau 141:32–33
4. Griggs DJ, Noguer M (2002) Climate change 2001: the scientific basis. Contribution of working group i to the third assessment

report of the intergovernmental panel on climate change. Weather 57:267–269

5. Paustian K, Babcock B, Hatfield J et al (2004) Agricultural mitigation of greenhouse gases: science and policy options. CAST (Council on Agricultural Science and Technology) Report R 141: 2004
6. Liu H, Jiang G, Zhuang H et al (2008) Distribution, utilization structure and potential of biomass resources in rural China: With special references of crop residues. Renew Sust Energ Rev 12: 1402–1418
7. Limmeechokchai B, Chawana S (2007) Sustainable energy development strategies in the rural Thailand: The case of the improved cooking stove and the small biogas digester. Renew Sustain Energy Rev 11:818–837
8. Zeng X, Ma Y, Ma L (2007) Utilization of straw in biomass energy in China. Renew Sustain Energy Rev 11:976–987
9. Zheng Y, Li Z, Feng S et al (2010) Biomass energy utilization in rural areas may contribute to alleviating energy crisis and global warming: a case study in a typical agro-village of Shandong, China. Renew Sustain Energy Rev 14:3132–3139
10. Edmeades DC (2003) The long-term effects of manures and fertilizers on soil productivity and quality: a review. Nutr Cycl Agroecosyst 66:165–180
11. Blanco-Canqui H, Lal R (2007) Soil structure and organic carbon relationships following 10 years of wheat straw management in no-till. Soil Tillage Res 95:240–254
12. Schofield R, Taylor AW (1955) The measurement of soil pH. Soil Sci Soc Am J 19:164–167
13. Bremner JM, Mulvaney CS (1982) Nitrogen-total. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Part 2: chemical and microbial properties, Agronomy Monograph 9. Agronomy Society of America, Madison, pp 595–624
14. Culley JLB (1993) Density and compressibility. In: Carter MR (ed) Soil sampling and methods of analysis. CRC Press, Boca Raton, pp 529–539
15. Change IPOC, Eggelstons S, Buendia L et al (2006) IPCC guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies (IGES), Hayama, Japan
16. Sommer SG, Olesen JE, Petersen SO et al (2009) Region-specific assessment of greenhouse gas mitigation with different manure management strategies in four agroecological zones. Global Change Biol 15:2825–2837
17. Bhattacharya S, Abdul Salam P, Runqing H et al (2005) An assessment of the potential for non-plantation biomass resources in selected Asian countries for 2010. Biomass Bioenergy 29: 153–166
18. Seufert V, Ramankutty N, Foley JA (2012) Comparing the yields of organic and conventional agriculture. Nature 485:229–232
19. Leifeld J, Angers DA, Chenu C et al (2013) Organic farming gives no climate change benefit through soil carbon sequestration. Proc Natl Acad Sci USA 110:E984
20. Gattinger A, Muller A, Haeni M et al (2013) Reply to Leifeld et al.: Enhanced top soil carbon stocks under organic farming is not equated with climate change mitigation. Proc Natl Acad Sci USA 110:E985
21. MacKenzie SH, Field CB, Raupach MR (2004) The global carbon cycle: integrating humans, climate, and the natural world. Island Press, Washington
22. Hocking MB (2006) Handbook of chemical technology and pollution control. Academic Press, London
23. Alvarez R (2005) A review of nitrogen fertilizer and conservation tillage effects on soil organic carbon storage. Soil Use Manag 21:38–52
24. Schlesinger WH (1999) Carbon sequestration in soils. Science 284:2095
25. Robertson GP (2004) Abatement of nitrous oxide, methane, and the other non-CO_2 greenhouse gases: the need for a systems approach. In: Field CB, Raupach MR (eds) The global carbon cycle: integrating humans, climate and the natural world. Island Press, Washington, DC, USA, pp 493–506
26. Gregorich E, Rochette P, VandenBygaart A et al (2005) Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada. Soil Tillage Res 83:53–72
27. Steinfeld H, Gerber P, Wassenaar T et al (2006) Livestock's long shadow: environmental issues and options. FAO, Rome, pp 101–104
28. Bemis G, Allen J (2005) Inventory of California greenhouse gas emissions and sinks: 1990 to 2002 update. In: California Energy Commission (ed) Proceedings of the Climate Change Advisory Committee Meeting and IEPR Committee Workshop on Global Climate Change in California
29. Cederberg C, Henriksson M, Berglund M (2013) An LCA researcher's wish list—data and emission models needed to improve LCA studies of animal production. Animal 7:212–219