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EVALUATION OF GREENHOUSE GAS EMISSIONS FROM THREE CONTRASTING INTEGRATED CROP AND LIVESTOCK PRODUCTION SYSTEMS DURING 1991-2016 IN GANSU OF CHINA

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This study was to evaluate the difference in greenhouse gas (GHG) emissions from 3 contrasting integrated crop and livestock production systems in Gansu of China from 1991 to 2016 using the life cycle assessment technique. The three systems were located in different regions: Hexi Oasis (dry arid, intensive crop/livestock production), Loess Plateau (semi-arid/semi-humid, dominated by extensive crop production) and Qinling Bashan Mountains (moist-subtropical, extensive crop/livestock production). The data used were collated from 525 farms (35 farms/county and 5 counties/region) thorough official statistical records and farm survey. The ANOVA analysis of average data from 2012 to 2016 indicated that Loess Plateau had a higher CO_2 equivalent (CO_2-eq) emission factor per kg DM product of maize and flaxseed than other 2 regions ($P < 0.05$), while a lower rate per kg beef carcass weight. Qinling Bashan Mountains had a lower emission factor for producing 1 ¥ of crop products than other 2 regions ($P < 0.05$). The evaluation of change in GHG emissions from 1991 to 2016 indicated that CO_2-eq per kg carcass of pork, beef, and lamb in the 3 production systems generally declined during this period, but emissions per kg DM of potato, rapeseed, and maize increased. However, CO_2-eq per ¥ of crop and livestock products tended to decrease from 1991 to 2016, driven mainly by market price and productivity. The present results provide the benchmark information for local policy makers and agricultural industries to make informed decisions for mitigation of GHG emissions from agricultural production in Gansu of China.

Keywords: Agricultural production, atmospheric temperature, greenhouse gas emission, life cycle assessment.

INTRODUCTION

Agricultural production is an important source of greenhouse gas (GHG) emissions, which in general accounts for 10-12% of the global anthropogenic GHG emissions (Herrero*et al*., 2011; Pishgar-Komleh*et al*., 2013; Bell *et al*., 2014). Methane (CH_4) and nitrous oxide (N_2O) are main GHG emission sources in the agricultural production sector, for example, CH_4 and N_2O emissions in China account for 50% and 92% of national total emissions, respectively (Dong*et al*., 2013). In China, total GHG emissions from agriculture production grew rapidly from 605 Mt CO_2-equivelant (CO_2-eq) in 1994 to 686 Mt CO_2-eq in 2007, and increased by approximately 80Mt per year since 2010 (Chen and Zhang 2010; Dong *et al*., 2013). There is evidence indicating that the effect on atmospheric temperature derived by climate change has impacted crop production and water use efficiencies in China (Dong *et al*., 2013; Guo*et al.*, 2010). Chinese government made commitments in the UN Climate Change Conference in 2009 to reduce carbon emissions per unit gross domestic product by 40-50% in 2020 (Cheng*et al.*, 2011). Therefore, there is an urgent need to provide detailed information on GHG emissions from crop and livestock production in different region of China, where the agricultural production systems are influenced by climate and other environmental factors. However, there is little information available on the accurate calculation of GHG emissions from agricultural production systems in Northwest China. The lack of such information could impact policy makers and agricultural industries to make informed decisions for mitigation of GHG emissions from agricultural production.

Agricultural production systems in China vary greatly in different regions, mainly due to the variations in climate, landscape and other environmental conditions. Even within Gansu Province, a region located in the centre of Northwest China, agricultural activities are commonly categorised in four contrasting areas: Loess Plateau, Hexi Oasis, Qinling Bashan Mountains and Tibet Plateau, mainly according to the climate variation (Ren*et al.*, 2009). The detailed information for the first three regions is presented in Table 1. The objectives of the present study were to evaluate the regional differences (Loess Plateau vs. Hexi Oasis vs. Qinling Bashan Mountains) in Gansu Province in GHG

Table 1. Elevation and climate condition in the three regions in Gansu Province of China selected for the present study.

	Hexi Oasis	Loess Plateau	Qinling Bashan Mountains
Climate condition	Dry arid	Semiarid & Semihumid	Moist subtropical
Elevation (m)	1170-1785	1450-1970	998-1492
Annual rainfall (mm)	70-156	330-450	402-774
Annual mean temperature (°C)	8.1-9.2	7.3-10.8	11.2-15.9
Annual frost-free days	130-210	154-186	197-284
Annual sunshine hours	2904-3260	2200-2766	1652-1911

emission factors associated with producing per unit of crop and livestock products and the effects of the economic development on GHG emissions per unit of crop and animal product from 1991 to 2016.

MATERIALS AND METHODS

The present study was to evaluate GHG emissions using the life cycle assessment (LCA) technique within farm gate for three contrasting agricultural production systems in Gansu Province of China. The CH_4 and N_2O emission data were converted into CO_2 equivalent (CO_2-eq) using their Global Warming Potential (GWP), with GWP of 25 for CH_4 and 298 for N_2O. The data used to calculate GHG emissions were from official records, farm survey data and published literature.

***Agricultural production systems in Gansu province*:** Gansu Province locates in Northwest China (92°13′-108°46′E, 32°31′-42°57′N and Figure 1) and covers an area 42.58×10^8 hectare with 1655 km long from east to west and 530 km wide from south to north (Li and Wang, 2010). There are significant differences in agricultural production conditions within the Province, e.g., climate (e. g. temperature, rainfall), landscape and soil type, thus agricultural production in the Province is divided geographically into four contrasting systems (Figure 1): Loess Plateau in north, Hexi Oasis in far northwest, Qinling Bashan Mountains in south and Tibet Plateau in southwest. Livestock production is the dominant agricultural activities in the Tibet Plateau region (An *et al.*, 2007) which is significantly different from the other regions where the integrated systems of crop and livestock production are in practice, therefore the Tibet Plateau is excluded from the present study.

There exist considerable differences in natural and climatic conditions in the three regions (Table 1). The Hexi Oasis has a rich underground water source for irrigation which enables a high input/output crop production. This region is also in favour of livestock production (cattle, sheep, pig and chicken) due to rich feed and water sources. However, crop production in the Loess Plateau mainly depends on natural rainfall which causes a large yearly variation in farm inputs and crop yields. Due to the uncertainty of feed supply, this area is mainly in practice of traditional livestock production. The Qinling Bashan Mountains is the only moist subtropical area in Gansu Province, but the lack of cultivated land is the main limited factor for agricultural activities in this region where farmland is located in both sides of valleys and on the top of flat Mountains areas. This region is the main production base for Chinese herbal medicine.

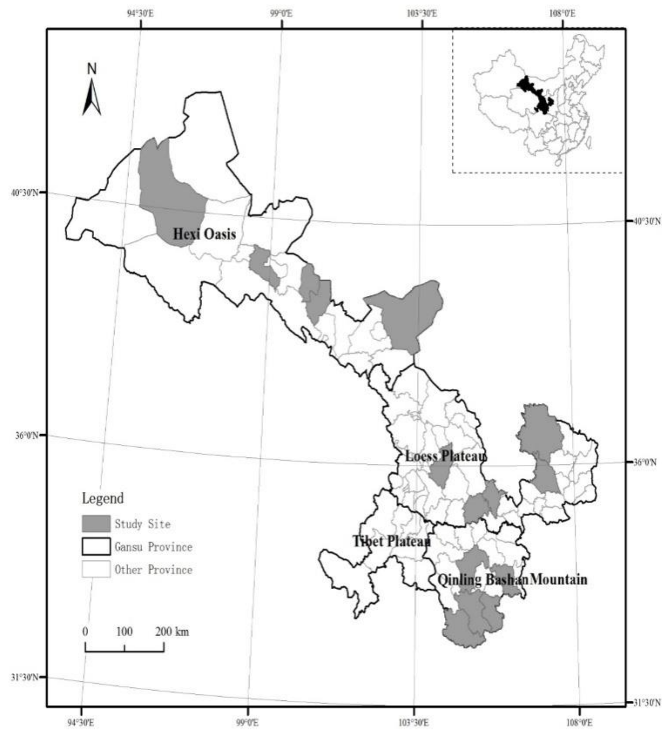

Figure1. Location of the fifteen counties in the three regions in Gansu Province of China selected for the present studies.

To facilitate comparison in GHG emissions from crop and livestock production among Loess Plateau, Hexi Oasis and Qinling Bashan Mountains, five typical counties were selected from each region to represent the regional average condition (Figure 1) namely Minqin, Linze, Guazhou, Ganzhou, Suzhou in Hexi Oasis; Huan, Zhenyuan, Jingning, Tongwei and Yuzhong in Loess Plateau; and Kang, Wen, Hui, Li and Wudu in Qinling Bashan Mountains.

***Data collection*:** Data used in the present study were collected from official statistical year books, farm surveys and published literature. The farm surveys were undertaken from 2006 to 2016 with data repeatedly collected from the same 525 farms per year using a face-to-face questionnaire method in the 15 counties (5 counties/region and 35 farms/county) selected for the present study. The five counties in each region were selected from statistical records to give an equidistant systematic sampling. These surveys were conducted by trained PhD and MSc students on a yearly basis during the period of October to December from 2006 to 2016. These students went to individual farms and interviewed a representative of each farm to obtain answers to all questions listed in the questionnaire. The questionnaire was designed to collect information in crop and livestock production. The information collected for crop production included: crop type, sowing area for each crop, production for each crop, seed source and amount of seeds used, type and rate of fertilizers used in different growth period, type and rate of pesticide used, fuel consumption for production (ploughing, tillage, transportation, harvesting and packaging), amount of plastic film, farm machine (type, life and working hours), electricity consumption for irrigation, yield of crop product. The information for livestock production collected through the farm survey included: species, livestock population, age, weight, yields of carcass weight, milk and egg, feed resources and feed consumption. The water content of crop product was collected in the published paper (Cheng, 2014).

The official statistical data in each county were collected from the Gansu Yearbooks from 1992 to 2009 (EBGY, 1992-2009), Gansu Development Yearbooks from 2010 to 2017 (EBGDY, 2010-2017), Gansu Rural Economy Yearbooks from 1992 to 2000 (EBGREY, 1992-2000) and Gansu Rural Yearbooks from 2001 to 2017 (EBGRY, 2001-2017). Crops collected from these Yearbooks included food crops (wheat, rice, maize, sorghum, millet, pros millet, soybean and potato) and economical crops (cotton, flaxseed, rapeseed, sunflower seed, hemp, beet, tobacco leaf, angelica and codonopsis pilosula). Livestock included pig, broiler, laying hen, beef cattle, dairy cattle and sheep. The information collected included rural human population, crop type, crop production area, crop productivity, farm inputs (e. g. fertilizers, pesticides, plastic film, diesel, and electricity), livestock breeding stock, slaughter numbers, feeds, carcass weight, and milk and egg production.

The price indices for farm products from 1991 to 2016 were collected from Gansu Yearbook from 1992 to 2009 (EBGY, 1992-2009), Gansu Development Yearbook for farm from 2010 to 2017 (EBGDY, 2010-2017) and Price Yearbook of China from 1992 to 2017 (EDPYC, 1992-2017).

***Calculation of GHG emissions from crop production*:** The official statistical yearbooks only presented information in total yearly usage of fertilizers, pesticides, plastic film, diesel and electricity in each county but no data were given for each crop in each county. Therefore, the allocation coefficients for these farm inputs were calculated using the data from the farm survey. For example, the allocation coefficients for yearly usage of fertilizers for a county were estimated using equation (1).

$$F_{ac} = \frac{T_{yf} \times TCL_y}{\sum_{i=1}^{18} CL_y(i) \times (C_{sn}(i) + C_{sp}(i) + C_{sk}(i) + C_{so}(i)) \times \mathrm{TCA}_y} \quad (1)$$

Where, F_{ac}, i represent allocation coefficient ($0<F_{ac}<=1$), crop number from spring wheat to codonopsis pilosula (spring wheat, winter, wheat, rice, maize, sorghum, millet, pros millet, soybean, potato, cotton, flaxseed, rapeseed, sunflower seed, hemp, beet, tobacco leaf, angelica and codonopsis pilosula), respectively; T_{yf}, TCL_y, TCA_y, $CL_y(i)$ represent total usage of fertilizer (kg/y), total cropland area (ha), total cultivated land (ha), cropland area of each crop (ha) collected from the official yearbooks, respectively; $C_{sn}(i)$, $C_{sp}(i)$, $C_{sk}(i)$, $C_{so}(i)$ represent the usage of N, P, K and other fertilizers from the survey data (kg/ha), respectively.

The GHG emissions for each category of crop using the LCA technique were estimated using the following equation (2).

$$CE_{crop} = \frac{AI_s \times EF_s + AI_f \times EF_f + AI_p \times EF_p + AI_{ie} \times EF_{ie} + AI_{pm} \times EF_{pm} + AI_{dc} \times EF_{dc} + RE_{CH4}}{CY_{DM}} \quad (2)$$

Where, CE_{crop}represents the GHG emissions from crop production (kg CO_2-eq/kg DM); AI_s represents quantities of seed DM (kg/ha);AI_f, AI_p, AI_{ie}, AI_{pm}, AI_{dc} represent the individual farm inputs from fertilizers, pesticides (kg/ha), electricity consumption for irrigation (kWh/ha), plastic films (kg/ha) and diesel consumption for farm machine (L/ha), respectively. Farm inputs of fertilizers, pesticide, electricity consumption, plastic film and diesel consumption were estimated using farmer survey data multiplied by F_{ac}, respectively;EF_s, EF_f, EF_p, EF_{pm}, EF_{ie}, EF_{dc}represent the emission factors from production of seed (kg/kg), fertilizer (kg/kg), pesticide (kg/kg), plastic film (kg/kg), electricity (kg/kWh) and diesel (kg/L) (Table 2), respectively;CY_{DM} represents the DM yield of crop. In particular, RE_{CH4} only represents the methane emissions from paddy field calculated using the following equation (3).

$$RE_{CH4} = Area_r \times Date_r \times EF_r \quad (3)$$

Where, RE_{CH4},$Area_r$, $Date_r$, EF_r represent the GHG emissions from paddy field (CO_2-eq/ha), harvested area of rice (ha), cultivation period (days), emission factors (Table 2), respectively.

In Gansu Province of China, there is little extra cost (e.g., no requirement for cleaning and packaging) for crop seeds before sale. Therefore, we assumed that the GHG emission factor for seed production was equal to that for grain production. The GHG emissions from seed production per kg of DM are calculated using equation (4).

$$EF_s = \frac{AI_f \times EF_f + AI_p \times EF_p + AI_{ie} \times EF_{ie} + AI_{pm} \times EF_{pm} + AI_{dc} \times EF_{dc} + RE_{CH4}}{CY_{DM} - AI_s} \quad (4)$$

Where, EF_s, EF_f, EF_p, EF_{pm}, EF_{ie}, EF_{dc}represent the emission factors from production of seed (kg/kg), fertilizer

Table 2.Emission factors used for calculation of GHG emissions for crop production.

Item	Sub-item	Emission factors	References
Fertilizer manufacture ($kg\ CO_2$-eq/kg)	N	6.380	Lu *et al*. (2008);Cheng *et al*. (2011).
	P	0.733	Dubey and Lal (2009);Cheng *et al*. (2011).
	K	0.550	Dubey and Lal (2009);Cheng *et al*. (2011).
Soil emissions from N fertilizer ($kg\ CO_2$-eq/kg)	CO_2 emissions	0.633	IPCC (2006); Adom*et al*. (2012).
	N_2Oemissions	6.205	Adom*et al*. (2012).
CH_4 emissions fromPaddy field ($kg\ CO_2$-eq/ha/day)	CH_4 emissions	32.50	IPCC (2006).
Pesticide manufacture ($kg\ CO_2$-eq/kg)	Herbicides	23.10	Lal (2004);Zeng *et al*. (2012).
	Insecticides	18.70	Lal (2004);Zeng *et al*. (2012).
	Fungicides	13.93	Lal (2004);Zeng *et al*. (2012).
Fuel ($kg\ CO_2$-eq/L)	Diesel	2.629	Cheng *et al*. (2011).
Plastic film manufacture ($kg\ CO_2$-eq/kg)	Plastic mulch	18.99	Cheng *et al*. (2011).
Electricity ($kg\ CO_2$-eq/kWh)	Electricity for irrigation	0.917	Shi *et al*. (2011).

Table 3. Emission factors used for calculation of GHG emissions for livestock production

Item	Sub-item	Emission factors	References
Feed processing ($kg\ CO_2$-eq/kg)	Maize	0.0102	Meng *et al*. (2014).
	Soybean	0.1013	Meng *et al*. (2014).
	Wheat	0.0319	Meng *et al*. (2014).
CH_4 emissions from enteric fermentation ($kg\ CO_2$-eq/head/year)	Pig	25	IPCC (2006).
	Beef cattle	1175	IPCC (2006).
	Dairy cattle	1525	IPCC (2006).
	Sheep	125	IPCC (2006).
CH_4 emissions from manure management ($kg\ CO_2$-eq/head/year)	Pig	50	IPCC (2006).
	Chicken	0.25	IPCC (2006).
	Beef cattle	25	IPCC (2006).
	Dairy cattle	250	IPCC (2006).
	Sheep	2.75	IPCC (2006).
N_2O emissions from manure management ($kg\ CO_2$-eq/head/year)	Pig	43.2	IPCC (2006);Zhou *et al*. (2007).
	Chicken	1.5	IPCC (2006);Zhou *et al*. (2007).
	Beef cattle	120.4	IPCC (2006);Zhou *et al*. (2007).
	Dairy cattle	106.7	IPCC (2006);Zhou *et al*. (2007).
	Sheep	62.3	IPCC (2006);Zhou *et al*. (2007).

(kg/kg), pesticide (kg/kg), plastic film (kg/kg), electricity (kg/kWh) and diesel (kg/L). AI_f, AI_p, AI_{ie}, AI_{pm}, AI_{dc}, AI_s, RE_{CH4} represent the individual farm inputs from fertilizers, pesticides (kg/ha), electricity consumption for irrigation (kWh/ha), plastic films (kg/ha), diesel consumption for farm machine (L/ha) and the GHG emissions from paddy field (CO_2-eq/ha), respectively. CY_{DM} represents the DM yield of crop (kg/ha).

***Calculation of GHG emissions from livestock production*:** The yearly GHG emissions for each livestock species were calculated using the equation (5), which were from four sources: feed production, feed processing, enteric fermentation and manure management.

$$CE_{Livestock} = \frac{TC_2O_{feed} + TCH_{4Enteric} + TCH_{4Manure} + TN_2O_{Manure}}{Livestock_{Yield}} \quad (5)$$

Where, $CE_{livestock}$ represents total GHG emissions of livestock (kg CO_2-eq/ kg CW, milk or egg), TC_2O_{feed}, $TCH_{4Enteric}$, $TCH_{4Manure}$, TN_2O_{Manure}, $Livestock_{Yield}$ represent the GHG emissions (kg CO_2-eq/year) from feed production, feed processing, ruminant enteric fermentation and manure management, total yield for each livestock species (kg CW, milk or egg/year), respectively.

The grains used for animal feedstuff in China are mainly maize, soybean and wheat (Xie*et al*., 2009; Meng*et al*., 2014). The GHG emissions from feed production and processing are calculated using equation (6).

$$TC_2O_{feed} = \sum_{i=1}^{6} Q_i \times t_i \times q_{ij} \times (ef_{j1} + ef_{j2}) \quad (6)$$

Where, TC_2O_{feed} and Q_i, represent total GHG emissions from feed production and processing (kg), the annual yield of livestock products (kg CW, milk or egg), respectively; t_i represents the coefficient of feed consumption for livestock from 1991 to 2016 (SBS, 1992-2017). The q_{ij} represents the allocation proportion of feedstuff. The allocation proportion of maize in feedstuff for pig, beef cattle, dairy cattle, sheep, broiler and laying hen in China were 55.7%, 37.0%, 46.8%, 62.6%, 57.0%, 63.3%, respectively (Meng *et al*., 2014). The allocation proportion of wheat used only for broilers was 5% (Meng *et al*., 2014). The ef_{j1} represents GHG emission coefficient of crop production (kg CO_2-eq/kg) calculated in the present study. *The* ef_{j2} represents GHG emission coefficient of crop processing (Table 3). The *i and j* represent type of livestock and feedstuff, respectively.

Methane emissions from enteric fermentationwere calculated using equation (7) of the Tier 1 methodologies of IPCC (2006).

$$TCH_{4Enteric} = \sum_{i=1}^{4} EF_i \times N_{(i)} \quad (7)$$

Where, $TCH_{4Enteric}$,EF_i, $N_{(i)}$, and *i* represent total methane emissions from enteric fermentation (kg CO_2 –eq/year), methane emission factor of livestock (Table 3), number of head of livestock species i, category of livestock, respectively. In particular, methane emissions from chicken were not calculated due to insufficient data (IPCC, 2006).

Methane emissions from manure management were calculated using equation (8) of the Tier 1 methodologies of IPCC (2006).

$$TCH_{4Manure} = \sum_{i=1}^{6} EF_i \times N_{(i)} \quad (8)$$

Where, $TCH_{4Manure}$, EF_i, $N_{(i)}$, *i* represent total methane emissions from manure management (kg CO_2-eq/year), methane emission factor from manure management of livestock (Table 3), number of head of livestock species i, category of livestock, respectively.

The N_2O emissions from manure management through direct and indirect emission sources were calculated using equation (9) of the Tier 1 methodologies of IPCC (2006).

$$TN_2O_{Manure} = [\sum_S [\sum_T (N_{(i)} \times Nex_{(i)} \times MS_{(i,S)})] \times (EF_{D(S)} + (\frac{Frac_{GasMS}}{100}) \times EF_{I(S)})] \times \frac{44}{28} \times 298 \quad (9)$$

Where, TN_2O_{Manure}, $N_{(i)}$, $Nex_{(i)}$,$MS_{(i,S)}$, $EF_{D(S)}$, *S*, *i*, 44/28, 298, $Frac_{GasMS}$, $EF_{I(S)}$represent total N_2O emissions from manure management (kg CO_2-eq/year), number of head of livestock species i, annual average N excretion per head of species i (kg N /head/year), fraction of total annual nitrogen excretion for each livestock species i that is managed in manure management system S, emission factors for direct N_2O emissions from manure management system S (kg N_2O-N/kg N) in manure management system S, manure management system, conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions, global warming potential, percent of managed manure nitrogen for livestock category T that volatilises as NH_3 and NO_x in the manure management system S (%), emission factor for indirect N_2O emissions from manure management system S (kg N_2O-N/kg N) in manure management system S, respectively.

In brief, Zhou*et al*. (2007) reported N_2O emissions from manure management including direct and indirect N_2O emissions in China were calculated using equation (10) based on the Tier 1 methodologies of IPCC (2006).

$$TN_2O_{Manure} = \sum_{i=1}^{6} EF_i \times N_{(i)} \quad (10)$$

Where, TN_2O_{Manure}, EF_i, and *i* represent total N_2O emissions from manure management (kg CO_2-eq/head/year), emission factor of livestock (Table 3), and category of livestock, respectively.

***Calculation of GHG emissions for agricultural products*:** Total GHG emission associated with production of per Chinese Yuan (¥, Chinese currency) of crop or livestock product was calculated using equation (11).

$$TGHG_{RMB} = \frac{\sum_{i=1}^{n} TGHG_{product(i)}}{\sum_{i=1}^{n} (YP_{product(i)} \times PRICE_{product(i)})} \quad (11)$$

Where, $TGHG_{RMB}$, $TGHG_{product\ (i)}$, $YP_{product\ (i)}$, $PRICE_{product\ (i)}$, and *n* respectively represent total GHG emissions (kg C_2O-eq/¥), total GHG emissions (kg CO_2-eq), yield of products (kg), price of products (¥), and product category, respectively. All prices of products were based on the market price indexes of these products in 2016, with the product price indices before 2016 being converted to the standard in 2016.

***Statistical analyses*:** The statistical programme used in the present research was Genstat16.0 (16^{th} edition; VSN International Ltd, UK). The differences in yield, GHG emissions per unit products and costs from the 3 contracting production systems in the regions (Hexi Oasis, Loess Plateau and Qinling Bashan Mountains) during the period of 2012 to 2016 were analysed using Linear Mixed Models with the 3 regions fitted as the fixed effect and year and county as random effects. Data of predicted means, standard error of differences and the level of different significance were calculated using internal algorithm of programme, respectively. The temporal variations in GHG emissions from 1991 to 2016 among the 3 contracting production systems in the 3 regions were also evaluated using the chart presentation.

RESULTS

***Crop and livestock production*:** The results of crop and livestock production from 2012 to 2016 are presented in Table 4. The yields (kg DM/ha) of maize, foxtail millet, soybean, potato, flaxseed, rapeseed, sunflower seed in the intensive production system in Hexi Oasis were significantly

Table 4. Statistical analysis on crop and livestock production among the three regions in Gansu Province of China from 2012 to 2016.

	Hexi Oasis	Loess Plateau	Qinling Bashan Mountains	SED	P-value
Crop products (kg DM/ha)					
Spring Wheat	7326	1285	-	153.7	<0.001
Winter Wheat	-	2517	3211	201.3	0.001
Rice	-	-	6191	-	-
Maize	7838a	3089b	3100b	218.0	<0.001
Sorghum	-	1273	1499	94.7	0.024
Foxtail millet	1638a	984c	1310b	116.8	<0.001
Broomcorn millet	-	537	-	-	-
Soybean	6584a	1432b	1456b	437.2	<0.001
Potato	10610a	2275b	2485b	277.2	<0.001
Cotton	1793	-	-	-	-
Flaxseed	3710a	962b	1530b	291.8	<0.001
Rapeseed	2834a	1912b	1576b	216.9	<0.001
Sunflower Seed	4396a	1372b	2015b	375.0	<0.001
Hemp	-	-	915	-	-
Sugar beet	25817	-	-	-	-
Tobacco leaf	-	1557	2087	360.3	0.155
Angelica	-	3626	3296	499.1	0.512
CodonopsisPilosula	-	3695	3126	770.5	0.464
Livestock products (kg/head/year)					
Beef carcass weight	102.4	103.6	104.0	2.014	0.715
Lamb carcass weight	15.41	15.21	15.20	0.222	0.571
Pig carcass weight	70.09	70.07	70.75	0.694	0.539
Chicken carcass weight	2.17	2.17	2.17	-	-
Egg	4.09	4.09	4.09	-	-
Milk	4959b	5302b	6399a	316.3	<0.001

[1] SED, standard error of differences.

a, b represent means with different letters in a row differed significantly (P< 0.05).

higher than those in other two regions (P< 0.001). Hexi Oasis also had higher yield of spring wheat (P<0.001) than Loess Plateau. For livestock production, there were no significant differences in production systems among the three regions.

Greenhouse gas emissions from crop production**:** The GHG emission factors for crop production from 2012 to 2016 are presented in Table 5. The GHG emissions per kg DM of products of spring wheat (P< 0.001), maize (P< 0.001), soybean (P< 0.05), potato (P< 0.001) and flaxseed (P< 0.001) in Loess Plateau were significantly higher than in Hexi Oasis. Loess Plateau also had higher GHG emission factors for production of winter wheat (P< 0.001), maize (P< 0.001), sorghum (P< 0.001), foxtail millet (P< 0.001), flaxseed (P< 0.001), and sunflower seed (P< 0.001) than in Qinglin Bashann Mountains. The GHG for potato production in Hexi Oasis was lower than in Qinglin Bashann Mountains (P< 0.001).

There was a tendency increase in GHG emission factors for crop production in the 3 regions from 1991 to 2016 (Fig. 2). For example, GHG emissions per kg DM of potato (Fig. 2a), rapeseed (Fig. 2b) and maize (Fig. 2c) production increased gradually from 1991 to 2016. The annual GHG emissions associated with potato production in Hexi Oasis during the period of 1991 to 2016 were lower than in other two regions (Fig. 2a), while the corresponding data for maize production in Loess Plateau were higher than in other two regions (Fig. 2c).

Table 5. Statistical analysis on GHG emission factors from crop and livestock production among the three regions in Gansu Province of China from 2012 to 2016.

Crop/livestock	HexiOasis	Loess Plateau	Qinling Bashan Mountains	SED[1]	P-value
CO_2-eq emissions for crop products (kg/kg DM)					
Spring Wheat	0.50	1.45	-	0.031	<0.001
Winter Wheat	-	0.68	0.51	0.032	<0.001
Rice	-	-	1.02	-	-
Maize	0.77b	1.11a	0.81b	0.039	<0.001
Sorghum	-	1.10	0.80	0.053	<0.001
Foxtail millet	1.58a	1.39a	0.81b	0.093	<0.001
Broomcorn millet	-	2.13	-	-	-
Soybean	0.36b	0.66a	0.62a	0.073	0.002
Potato	0.16c	0.35b	0.44a	0.020	<0.001
Cotton	2.50	-	-	-	-
Flaxseed	0.52b	1.10a	0.50b	0.080	<0.001
Rapeseed	0.82a	0.57b	0.56b	0.054	<0.001
Sunflower Seed	1.16a	1.38a	0.75b	0.117	<0.001
Hemp	-	-	0.78	-	-
Sugar beet	0.14	-	-	-	-
Tobacco leaf	-	0.43	0.26	0.038	<0.001
Angelica	-	0.34	0.23	0.044	0.011
Codonopsispilosula	-	0.29	0.37	0.059	0.201
CO_2-eq emissions for livestock products (kg/kg)					
Beef carcass	26.31a	24.98b	26.74a	0.395	<0.001
Lamb carcass	9.77	9.54	9.23	0.294	0.187
Pig carcass	4.73	4.67	4.69	0.049	0.438
Chicken carcass	2.67	2.67	2.67	-	-
Egg	2.06	2.06	2.06	-	-
Milk	0.69a	0.65a	0.54b	0.038	0.001

[1] SED, standard error of differences.
a,b,c represent means with different letters in a row differed significantly ($P< 0.05$).

Table 6. Statistical analysis on GHG emission per Chinese currency (kg CO_2-eq/¥) for crop and livestock production among the three regions in Gansu Province of China from 2012 to 2016[1].

Agriculturalproducts	Hexi Oasis	Loess Plateau	Qinling Bashan Mountains	SED[2]	P-value
Crop	0.23a	0.23a	0.12b	0.016	<0.001
Livestock	0.22	0.21	0.21	0.009	0.199
Crop & livestock	0.22a	0.22a	0.16b	0.012	<0.001

[1]The price index for all crop and livestock products from 2012 to 2015 were converted to the standard in 2016.
a,b represent means with different letters in a row differed significantly ($P< 0.05$).[2] SED, standard error of differences.

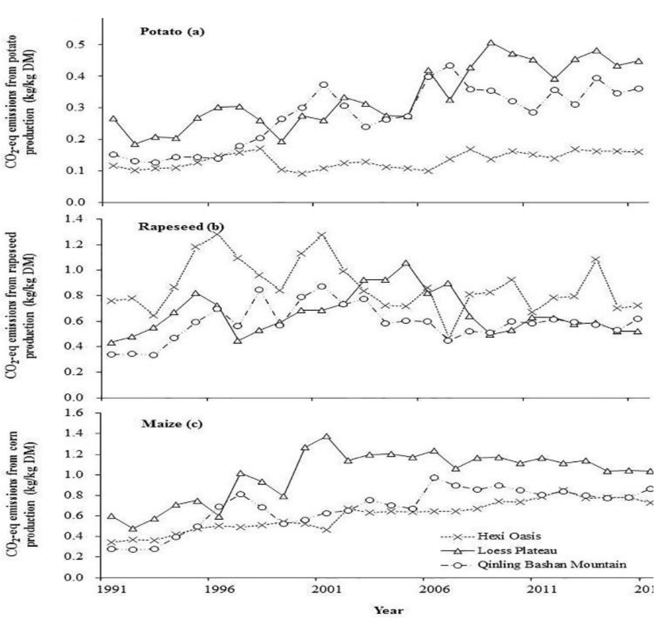

Figure 2. The variations in GHG emission factors for potato, rapeseed and maize production in Hexi oasis (×), Loess Plateau (△) and Qinling Bashan Mountains (○) regions from 1991 to 2016.

***Greenhouse gas emissions from livestock production*:** The GHG emissions from livestock production from 2012 to 2016 are presented in Table 5. Production of 1 kg CW of beef in Loess Plateau resulted in significantly lower GHG emissions than in other two regions ($P< 0.001$). However, there was no significant difference in GHG emission factors for production of lamb or pig CW among the 3 regions.

There was a tendency of decrease in GHG emission factors from livestock production in the 3 regions from 1991 to

2016 (Fig. 3). For example, GHG emissions per kg of CW of pig (Fig. 3a), beef cattle (Fig. 3b) and sheep (Figure 3c) production decreased gradually from 1991 to 2016. Qinling Bashan Mountains had a higher GHG emission rate per kg of lamb CW from 1991 to 2006 than other 2 regions (Fig. 3c).

***Greenhouse gas emissions from whole agricultural production systems*:** The GHG emissions per Chinese Yuan (¥) of agricultural products from 2012 to 2016 are presented in Table 6. The GHG emissions per ¥ of crop or crop plus livestock product in Qinling Bashan Mountains were lower than in Hexi Oasi and Loess Plateau ($P< 0.001$), while the differences between the latter 2 regions were not significant. However, there were no differences in GHG emissions per ¥ of livestock product among the 3 regions.

There was a tendency of decrease in GHG emission factors for production of 1 ¥ of products of crop, livestock or crop plus livestock in the 3 regions from 1991 to 2016 (Fig. 4). During this period, GHG emissions per ¥ of crop product (kg CO_2-eq/¥) reduced from 0.36 to 0.26 in Hexi Oasis, 0.36 to 0.22 in Loess Plateau and 0.28 to 0.12 in Qinling - Bashan Mountains (Fig. 4a). Similar results for livestock production were also observed (Fig. 4b), with reduction (kg CO_2-eq/¥) from 0.65 to 0.22 in Hexi Oasis, 0.68 to 0.21 in Loess Plateau and 0.55 to 0.19 in Qinling Bashan Mountains. The corresponding results of reduction for crop plus livestock production are presented in Figure 4c.

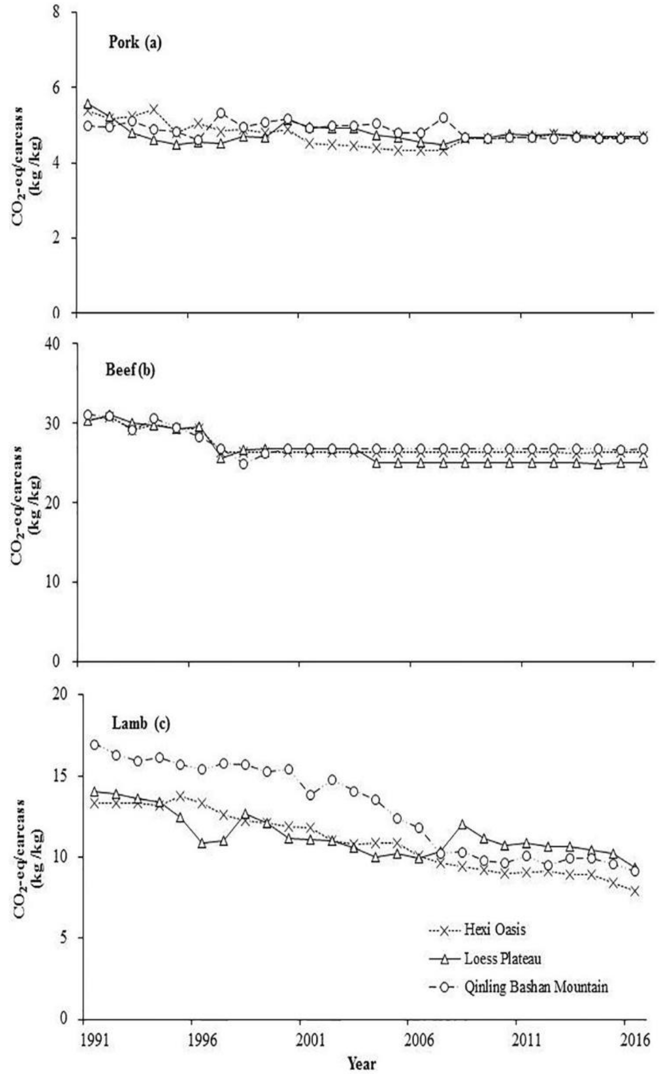

Figure 3. **The variations in GHG emission factors per kg pork, beef and lamb product in Hexi oasis (×), Loess Plateau (△) and Qinling Bashan Mountains (○) regions from 1991 to 2016.**

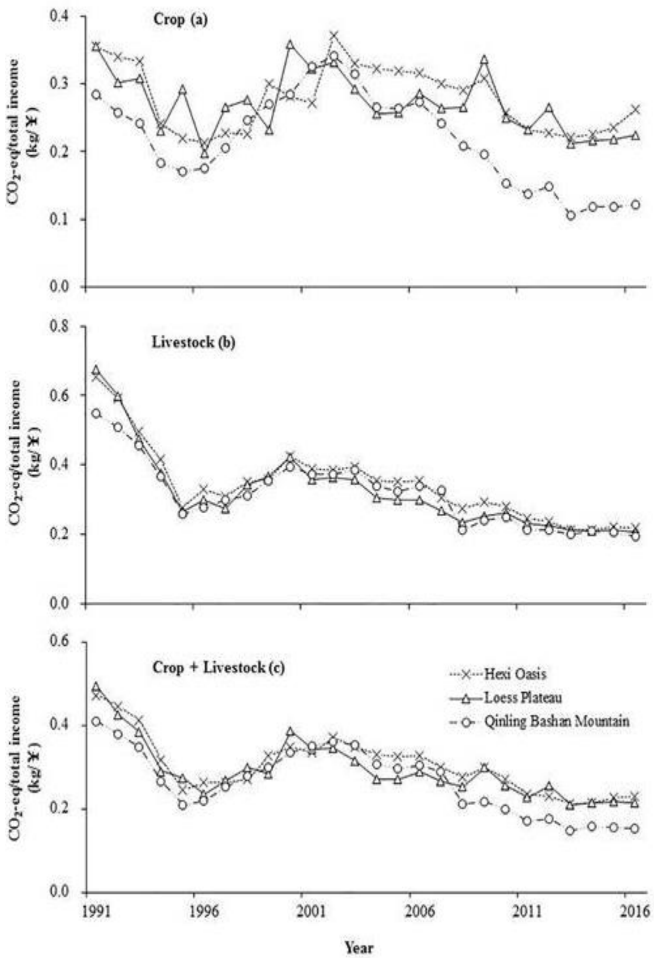

Figure 4. The variations in GHG emissions per Chinese Yuan (¥) product of crop and livestock in Hexi oasis (×), Loess Plateau (△) and Qinling Bashan Mountains (○) from 1991 to 2016 (all price indexes for crop and livestock production were based on the standard in 2016).

DISCUSSION

***Greenhouse gas emissions from crop production*:** The GHG emission factors for crop production can be influenced by variations in farm input and output capacities including crop yield, environment conditions, production systems, management regimes, fuel and electricity input, etc. Therefore, it is very difficult to make direct comparisons in GHG emission factors for certain crop production among countries. Even within China, our GHG emission factors for winter wheat, maize and rice are much higher than those (0.44, 0.29, 0.62 kg CO_2-eq/kg products, respectively) estimated using LCA by Zeng*et al*. (2012) in Ningxia Hui Autonomous Region of China, a province north of Gansu Province. The difference could, however, be partially attributed to the methodology used by Zeng *et al*. (2012) which did not take account of soil N_2O emissions for all 3 crops and paddy field CH_4 emissions for rice production. However, the present GHG emission factors for some crop products are comparable to those published elsewhere. For example, our emission factor for potato production is closed to that (0.44 vs. 0.50 kg CO_2-eq/ kg DM) in the UK (Audsley and Wilkinson, 2014); for rapeseed production is similar to that (0.57 vs. 0.61 kg CO_2-eq/ kg DM) in Germany (Felten*et al.*, 2013); for sugar beet production is close to that (0.14 vs. 0.15 kg CO_2-eq/ kg DM) in Iran (Yousefi*et al*., 2014). Nevertheless, our GHG emission factor for spring wheat production is higher than that (0.50 vs. 0.357 kg CO_2-eq/ kg DM) in Canada (Pandey and Agrawal, 2014), and for sunflower seed production is higher than those (0.75-1.38 vs. 0.47 kg CO_2-eq/kg DM) in Chile (Iriarte and Villalobos, 2013).

As indicated previously, the differences in weather condition and water resource significantly influence the crop production in Gansu Province of China. Hexi Oasis has rich underground water and sunny/warm weather from late spring to early autumn, so it adopts a high input/output system with the highest crop yields and farm inputs (e.g., fertilizers, electricity and diesel consumption) in Gansu Province. Although farm inputs in Loess Plateau were much higher than in Qinling Bashan Mountains from 1991 to 2016, there were no significantly differences in crop yields between the 2 regions. The crop production in Loess Plateau depends on natural rainfall, so crop yields in this region varied considerably during the last 25 years. These conditions significantly influenced GHG emission factors for crop production among the 3 regions in Gansu Province selected for the present study. For example, the average yields of maize and potato from 2012 to 2016 in Hexi Oasis were significantly higher than those in Loess Plateau and Qinling Bashan Mountains, so the GHG emission factors of these crops (CO_2-eq/DM of product (kg/kg)) in Hexi Oasis were lower than that in other 2 regions.

The GHG emission factor per ¥ for crop production not only relates to the GHG emissions for crop production, but also relies on the price index. There was a large variation in crop product prices in Gansu Province of China from 1991 to 2016. For example, the price of agricultural products in China in 1996 rose 90.8% compared to that in 1992 (SONBSA, 2008). This change plus other factors resulted in a dramatic decrease in GHG emission factors in the 3 regions selected in the present study from 1991 to 1996 (Figure 4). In general, the growth rate of total income per farm was higher than that of farm inputs. Therefore, the GHG emissions per ¥ for crop production decreased gradually from 1991 to 2016.

The largest contribution source to GHG emission factors was from the fertilizer input, which accounted for 73% to 91% of total emissions in the crop production. This contribution in Gansu Province was much higher than the average level of 57% in China (Cheng *et al*., 2011).Hillier*et al*. (2009) reported that GHG emissions derived from nitrogen fertilizer input accounted for more than 75% in primary crop production in the UK. Mohammadi*et al*. (2014) reported that fertilizer and biocide inputs were primary sources for CO_2 and N_2O emissions for crop production in north Iran. According to official reports (EBGREY, 1992-2000; EBGRY, 2001-2017), fertilizer inputs and crop yields in the 3 regions selected in the present study increased gradually from 1991 to 2016. However, with increasing inputs of other sources, e.g., pesticide, diesel, electricity and plastic film, the annual growth rate of crop yield was lower than that of GHG emissions from 1991 to 2016. As shown in Figure 2, GHG emissions per kg of crop product (e.g., potato, rapeseed, maize) gradually increased from 1991 to 2016. Thus, increasing the efficiency of utilisation of fertilisers or/and use of alternative fertilizers (e.g., livestock manure) is an important step towards to development of a low GHG emission and sustainable crop production.

***Greenhouse gas emissions from livestock production*:** Our GHG emission factors for livestock production are comparable to those published elsewhere. For example, our emission factor for pork production is similar to that (4.67-4.73 vs. 4.66 kg CO_2-eq /kg pork) recommended by FAO (FAO, 2013). Our beef emission factors (24.98-26.74 kg CO_2-eq /kg beef) are within the range (23.10 - 29.l7 CO_2-eq/kg beef) reported by Mogensen*et al*. (2015) in USA. The present average lamb emission factor (9.51 kg CO_2-eq/kg lamb) is marginally above the high end of range for lamb production (9.3 CO_2-eq/kg lamb) in Australia (Harrison *et al*., 2014). However, the present GHG emission factors for beef, pork and chicken production in Gansu Province are much higher than the average values in China (20.51, 4.24 and 2.24 kg CO_2-eq/kg CW) reported by Huang*et al*. (2015) using the carbon footprint assessment method within farm-gate.

The livestock production systems in Gansu Province of China are different from developed countries in the world, in terms of livestock breed, productivity, feed sources, feeding regime and management systems. In Gansu Province, the majority of beef cattle, sheep and poultry production is managed under the free-range feeding regime with low inputs and low production levels. For example, beef cattle in Gansu Province are not the breed selected for beef production but originated as draft animals for ploughing crop field.

With the improvement in levels of livestock production from 1991 to 2016, the GHG emission factors for livestock products decreased slowly in the 3 regions of the present study (Figure 4). This led to a tendency of decreased GHG emissions per ¥ of livestock products in the 3 regions during the same period. In accordance with the results of Zhou*et al*. (2007) and Xue*et al*. (2014), the present study also found that the contribution of methane emissions from enteric fermentation increased gradually from 1991 to 2016. This contribution is of course mainly from ruminant animals (e.g., cattle and sheep) because pigs and poultry have much smaller methane rates from enteric methane emissions (IPCC, 2006). Livestock animals can consume feeds which are not suitable or less favourable as human food, especially cattle and sheep which can convert forage into high protein food (meat and milk) for human consumption. This places Gansu Province in a favourite position in China, because Gansu Province has relatively much more grassland resources than Provinces in eastern and southern China. Therefore, it is necessary to change the present agricultural structure in Gansu Province through increasing the rate of livestock farming in the whole agriculture production systems (Ren *et al*., 2009).

***Uncertainty of GHG emissions assessment*:** Many factors could add weights to the uncertainty of the present assessment of GHG emissions from typical agricultural production systems in Gansu Province. Firstly, although the five counties selected from each region were typical of the production system in the region, these five counties might not fully cover all variations in crop and livestock production systems within each region. Secondly, the official data collection system in China might not be as good as that in developed country (Xue *et al*., 2014). For example, there was no detailed information on farm inputs (e.g., N fertiliser) for each crop production in the statistical yearbooks, the allocation coefficient for farm inputs for each crop production was calculated in the present study using data collected from the farm surveys. In addition, the emission factors for P and K fertilizers and pesticides in China were estimated using those reported by Cheng *et al*. (2011) and Zeng *et al*. (2012) which originated from other countries. The use of the Tier 1 method proposed by IPCC (2006) also added uncertainty to present emission factors for livestock production, because this method does not take account of the effects of animal and diet factors on enteric methane emissions. In a long term period, CO_2 emissions from soil on a global scale were estimated to contribute less than 1% to the GWP of agriculture (Liang*et al*., 2013). Therefore, carbon dynamic and CO_2 emissions from soil were not considered in whole crop systems in the present study. To sum it up, although above uncertainties might add errors to the present estimation of GHG emissions in the 3 regions of Gansu Province in China, our results could provide benchmark information for the Chinese government to develop appropriate policies to reduce GHG emissions from crop and livestock production in northwest of China. However, further improvement is required in future to upgrade the current evaluation of GHG emissions from agricultural production systems in Gansu Province.

Conclusion: A range of models were developed in the present study using the life cycle assessment technique. These models were used to evaluate the differences in GHG emission factors for crop and livestock production from 3 contrasting integrated crop and livestock production systems in Gansu Province of China. The statistical analysis of data from 2012 to 2016 indicated that various farming inputs and conditions (e.g., weather, soil type and landscape) had significant impacts on GHG emission factors for producing 1 kg DM products of maize and flaxseed and 1 kg of beef carcass. The evaluation of the temporal variations revealed that GHG emissions per kg DM of maize, rapeseed and potato production across the 3 production systems gradually increased from 1991 to 2016, while GHG emission factors per kg carcass of pork, beef and lamb gradually decreased during the same period. Although a range of uncertainties might influence the accuracy for calculation of these emission factors, the present data could provide the benchmark information for Chinese authorities to make informed decisions for mitigation of GHG emissions from contrasting agricultural production systems in northwest China.

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