Environ Earth Sci (2016) 75:121
DOI 10.1007/s12665-015-4777-9

ORIGINAL ARTICLE

Drivers of agricultural carbon emissions in Hunan Province, China

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Received: 1 December 2014 / Accepted: 12 July 2015 / Published online: 6 January 2016

Abstract This paper estimates carbon emissions from agricultural production in China's Hunan Province during the period from 1998 to 2012. It also analyzes trends in the development of agricultural carbon emissions and the decoupling relationship between carbon emissions and the agricultural output of Hunan. In this study, emissions from two key segments of the agricultural sector were quantified: (1) crop production and (2) livestock and poultry production (singular). A combined method of principal component analysis (PCA), multiple regression analysis, and decoupling analysis was employed to assess the drivers of agricultural carbon emissions. This showed that there was a weak and unstable decoupling relationship between agricultural carbon emissions and their output value during the period of study. The PCA revealed that two main factors—urbanization rate and nitrogen fertilization per acre—explained 92.51 % of the variation in the 11 factors that affected carbon emissions from crops. Also, two main factors (i.e., agriculture per capita GDP and the ratio of beef production to total livestock production) explained 86.27 % of the variation in nine factors that affected carbon emissions from the livestock and poultry industry. Using the PCA scores as independent variables, a multiple regression analysis of carbon emissions from the crop industry and the livestock and poultry industry showed the following patterns. (1) Theoretically, given a 10 % reduction in nitrogen fertilization per acre, crop carbon emissions would decrease by 519 units. If the rate of urbanization were to increase by 1 %, crop carbon emissions would increase by 83 units; (2) similarly, a 1 % reduction in the beef: total livestock and poultry production ratio would reduce carbon emissions from that industry by 329 units, and with "agricultural per capita GDP" growth of 1 unit, those emissions would increase by 0.354 units. The results of this study contribute to evaluating the sustainability of agricultural production in the region, and they provide a foundation of knowledge for future development of related agricultural mitigation policy and low-carbon agricultural technology.

Keywords Agricultural carbon emissions · Decoupling theory · Energy consumption · Livestock production · Multiple regression analysis · Principal component analysis

Introduction

Agriculture forms the foundation of China's national economy. The large contribution of this industry to carbon emissions in the world's most populous nation is therefore receiving growing attention, especially from the country's federal government and research community. Further, agriculture is the world's second-largest source of greenhouse gas (GHG) emissions (FAO 2009), accounting for about 20 % of global carbon emissions from human activities (Paustian and Vernon 1998). Analyses indicate

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that worldwide, 70 % of current atmospheric methane originates from agricultural production (Mosier et al. 1998), and that agricultural activities contribute roughly half of anthropogenic CH_4 and N_2O emissions, at 47 and 58 %, respectively (IPCC 2006). China produces the most GHG emissions of any developing country; its total agricultural emissions were 604 Mt CO_2 eq in 1994 and 686 Mt CO_2 eq in 2007, accounting for 16.57 and 9.2 % of the country's total GHG emissions, respectively (NDRC 2004; Chen and Zhang 2010).

Agriculture is not only a major source of greenhouse gas emissions, but conversely also one of the economic sectors that are most vulnerable to climate change. Agricultural production is tightly coupled with the condition of the environment—efficient agricultural production will inevitably require high investment of material inputs, and the attendant high-energy consumption and high emissions have become a primary cause of the deterioration of natural resources and environmental conditions in China. Currently, population expansion and economic development pressure prevent the increase of agricultural production in developing countries via expansion of the area of arable land. Instead, high-yield crop varieties, fertilizers, pesticides, agricultural machinery and other modern agricultural investments are the only way to increase yield per unit area. The dependence of "carbon-intensive agriculture" on fossil fuels has a much more severe impact on natural resources, the environment, and climate, due to increasing agricultural carbon emissions. If agricultural production continues to be dependent on fossil fuels, the influence of agriculture will continue to exacerbate global climate change (Smith et al. 2007b; Verge et al. 2007).

The most commonly used approach to measure agricultural carbon emissions in China is the IPCC inventory and its methods. The total amount of agricultural carbon emissions (i.e., the sum of emissions from crop and livestock production) was assessed, to analyze the factors that drive it (Dong et al. 2013; Min and Hu 2012; Tian and Zhang 2013). Notably, for different sources of carbon emissions from the crop industry and from the livestock and poultry industry, the estimated inventory of emissions and their driving factors varied, especially for systems with a high production of livestock and poultry (i.e., in terms of output value and yield). For example, in the actual measurement of agricultural carbon emissions, the crop industry produces a large proportion of emissions from material inputs (such as chemical fertilizers and pesticides), while emissions from the livestock and poultry industry mainly involve livestock enteric fermentation and manure management (rather than agricultural materials), namely the external consumption of energy. Therefore, if only for the purpose of studying the factors that influence total agricultural carbon emissions, the results would certainly be biased.

The objectives of this study were to: (1) analyze dynamic variation in and development of agricultural carbon emissions, based on measures of emissions from the crop industry and the livestock and poultry industry in Hunan; (2) analyze the relationship between agricultural production and associated carbon emissions in the region; (3) quantitatively analyze the relationship between carbon emissions from those agricultural industries and the factors that influence emissions; (4) analyze the potential and pressure for mitigation of agricultural carbon emissions, thereby providing a theoretical and policy basis for the assessment of such emissions, along with approaches for reduction such as the development of low-carbon agricultural technology.

To achieve these objectives, carbon emissions from the crop industry were assessed independently of those from the livestock and poultry industry. Our approach involved time series analysis, which is a useful tool in environmental and economic research including experimental, modeling, and policy studies (Lee and List 2004; Verbeke and De Clercq 2006). The related potential drivers of emissions were analyzed using principal component analysis (PCA) and multiple regression analysis. PCA is a method of ordination that is often used to extract relevant information from multivariables, complex data sets. It can functionally eliminate multicollinearity among independent variables, generating new variables that can be used as predictors in regression analysis (Rajab et al. 2013). This combination of statistical approaches is therefore used widely to identify the key factors that drive energy, environmental, and economic dynamics (e.g., Hillier et al. 2009; Shu and Nina 2011; Tian et al. 2012a; Braun et al. 2014; Zhang et al. 2014).

An additional step of our approach drew upon decoupling theory, which is used to study the causal relationship between resource consumption and economic development. It is especially useful in energy environment analysis and is thus important in the empirical study of links between economic development and carbon emissions (Guivarch and Mathy 2012; Tian et al. 2012b). Combined, these analyses were used to achieve the overall purpose of this paper, namely to better understand the dynamics of agricultural carbon emissions in Hunan in order to facilitate future efforts to mitigate their contribution to global climate change.

Description of the investigated area

The study identified the key factors that affect agricultural carbon emissions in Hunan, with a view to evaluating the sustainability of agricultural production in the region. Hunan is a province in south-central China, located from 25°–30°N to 108°–114°E. It covers ~211,800 km^2, accounting for 2.2 % of China's land area which places it 10th among the country's provinces and direct-controlled municipalities (and first, within the central part of the country). Hunan Province has 14 cities, with a resident population of 66.9 million at the end of 2013, ranking seventh among all provinces in China.

Roughly half of the province's total area consists of mountainous and hilly landscapes. In comparison, its arable area of 3.8 million ha represents 17.9 % of the province's land and 3.1 % of the national availability of arable soils. The subtropical monsoon climate provides ample heat and concentrated rainfall for crop production, although there is an annual drought during summer. Hunan is an important base of grain production, ranking seventh among the provinces in 2012. It supports the nation's highest rice acreage and yield, along with a high output of other major agricultural products including cotton, oil, tobacco, and ramie. Hunan is the most important province in terms of pig farming.

Materials and methods

Several steps were involved in the process of estimating carbon emissions from agricultural production in Hunan (Fig. 1). The period of time used in the analysis was 1998–2012.

Methods for calculation of carbon footprints

Agricultural carbon emissions result mainly from the processes of growth and development of cultivated plants, and material and energy recycling in the natural environment. Various studies of agricultural carbon emissions have been conducted based on the framework of Johnson (2007), (IPCC 2006; Schneider et al. 2007; Hillier et al. 2009; Cheng et al. 2011; Min and Hu 2012; Tian et al. 2012a; Tian and Zhang 2013). Based on that body of research, the following four key sources of agricultural carbon emissions are considered in this paper: (1) those caused by the input of agricultural materials (e.g., chemical fertilizers, pesticides, and diesel oil) and other direct and indirect emissions caused by agricultural energy consumption (e.g., direct N_2O emissions due to nitrogen fertilization), as shown in Table 1. (2) CH_4 and other GHG emissions from rice production; the typical CH_4 emissions from rice paddies are shown in Table 2. (3) Carbon emissions from agricultural land use, including loss of the soil organic carbon pool due to soil tillage, disposal of agricultural waste, and CH_4 and N_2O emissions caused by straw burning (calculated based on Cao et al. 2007). The loss of soil, N_2O emissions caused by damage to topsoil, and N_2O emissions from soil are shown in Table 3. (4) Carbon emissions caused by feeding animals, especially ruminants. The GHG emission output factors from the livestock and poultry industry are shown in Table 4. In this paper, the definition of agricultural carbon emissions encompasses only the harvesting of crops and livestock/poultry products, excluding any emissions from the processing and transportation of agricultural products.

Agricultural carbon emissions

Using the above limits to the definition of agricultural carbon emissions, the formula for calculating the emissions was established as:

$$e = \sum E_i = \sum T_i \cdot \sum \delta_i \tag{1}$$

where E represents the total agricultural carbon emissions, Ei represents each source of carbon emissions, Ti is the amount of carbon emissions from carbon source i, and δi is the emission factor for carbon source i. To facilitate the analysis, all values were converted to the units of CO_2 equivalents (CE).

The amount of direct N_2O emissions resulting from nitrogen fertilization was calculated as (IPCC 2006):

$$CF = F_N \times \delta_N \times \frac{14}{28} \times 290 \times \frac{12}{44} \tag{2}$$

where CF represents the direct N_2O emissions from nitrogen fertilization (converted to CE), F_N represents the amount of nitrogen fertilizer applied, δ_N is the N_2O emission factor (t $N_2O\text{-}Nt^{-1}N$ fertilizer) caused by nitrogen fertilization, 44/28 represents the molecular weights of N_2 compared to N_2O, 298 is the net Global Warming Potential (GMP) per century, and 12/44 represents the molecular weights of C compared to CO_2 (IPCC 2006).

Annual rearing of livestock

During the measurement of GHG emissions from the livestock and poultry industry, the measure of average annual rearing of livestock must be adjusted based on the slaughter rate (IPCC 2006; Hu and Wang 2010; Min and Hu 2012). Since the slaughter rates for pigs, rabbits, and poultry are all greater than 1, with respective average life cycles of 200, 105, and 55 days, the average annual amount of rearing was adjusted according to the following formula:

$$N_i = Days\_alive_i \times M_i/365 \tag{3}$$

where N_i is the average annual amount of rearing for the ith kind of livestock, Days_ alive$_i$ is the average life cycle of animal type i, and M_i is the annual yield of animal type i (i.e., slaughter).

For types of livestock and poultry with a slaughter rate of less than 1, the average amount of annual rearing was adjusted according to the breeding stock at the end of the year:

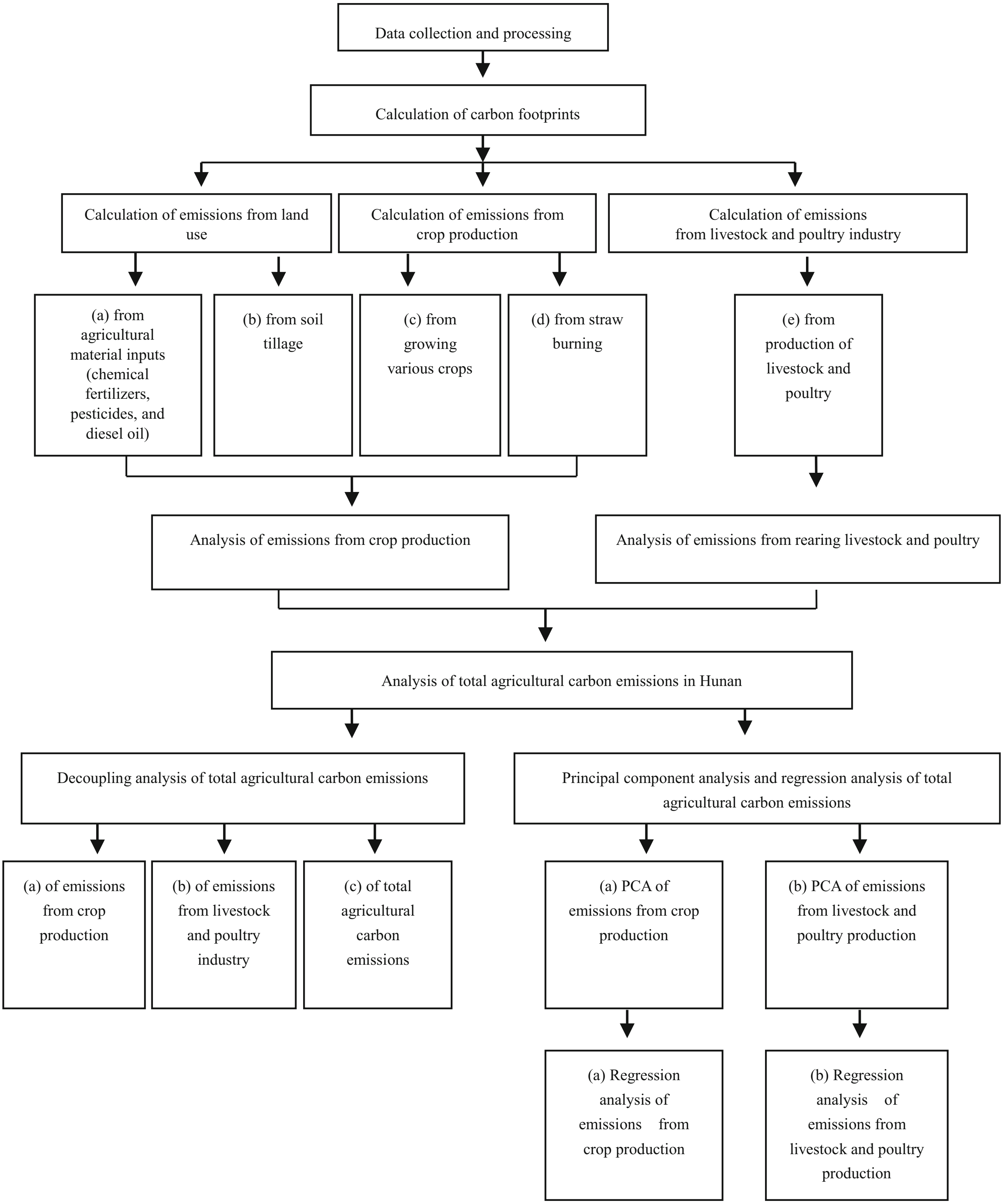


Fig. 1 An overview of the steps in the methodology of this study

Table 1 Sources of agricultural carbon emissions from different material inputs, energy consumption, and straw burning

Source of emissions	Rate of emissions	References
Fertilizer	1.74 tC t^{-1} *N* fertilizer	Lu et al. (2008)
	0.20 tC t^{-1} *N* fertilizer	Dubey and Lal (2009)
	0.15 tC t^{-1} *N* fertilizer	
N fertilizer induced N_2O	Dry cropland, 0.01 $tN_2O\text{-}Nt^{-1}$ fertilizer-*N*	IPCC (2006)
	Rice paddy, 0.003 $tN_2O\text{–}Nt^{-1}$ fertilizer-*N*	
Pesticides	4.93 tC t^{-1} pesticide	West and Marland (2002)
Plastic film	5.18 tC t^{-1} film	NDRCC (2010)
Diesel oil for machinery	7.74×10^{-4} Ct^{-1} diesel oil	BP China (2007)
Electricity for irrigation	0.74 $tCha^{-1}$	BP China (2007); Qian et al. (2007); Peng et al. (2009)
Tillage	0.3126 $tCkm^{-2}$	Wu et al. (2014)
Straw burning	CH_4 0.72 g kg^{-1}	Cao et al. (2007)
	N_2O 3.007 g kg^{-1}	

Table 2 Methane emissions throughout the growth cycle of rice

Emission source	Rate of emissions ($g.m^{-2}$)	Stage of growth cycle	References
Early rice	14.71	85 days	Min and Hu (2012); Tian and Zhang (2013)
Late rice	34.10	100 days	
Mid-season rice	56.28	105 days	

Table 3 Nitrous oxide emissions from soil for various crops

Emission source	Rate of emissions (kg hm^{-2})	References
Rice	0.24	Wang (1997)
Winter wheat	2.05	Pang et al. (2011)
Soybean	0.77	Xiong et al. (2002)
Maize	2.53	Wang and Su (1993)
Vegetables	4.21	Qiu et al. (2010)
Other dry crops	0.95	Wang (1997)

Table 4 Carbon emissions from the rearing of major types of livestock and poultry

Type of animal	Rate of CH_4 emissions (kg $head^{-1}$ a^{-1})		Rate of N_2O emissions (kg $head^{-1}$ a^{-1})	References
	Enteric fermentation	Manure		
Cows	61	16	1	IPCC (2006); Hu and Wang (2010)
Buffalo	55	2	1.34	
Cattle	47	1	1.39	
Horses	18	1.64	1.39	
Pigs	1	4	0.53	
Goats	5	0.17	0.33	
Sheep	5	0.15	0.33	
Rabbits	0.254	0.08	0.02	
Poultry	n/a	0.02	0.02	

$$N_{\mathrm{i}} = \left[C_{it} + C_{i(t-1)}\right]/2 \tag{4}$$

where N_{i} is the average annual amount of rearing animal type i; C_{it} and C_i $(t - 1)$ are the breeding stock at the end of years t and $t - 1$ for animal type i.

Carbon intensity and carbon efficiency

In this paper, carbon intensity (CI) refers to the carbon emissions per unit of output, which can be used to estimate the influence per unit of output on carbon emissions and the cost-effectiveness of carbon emissions. It is expressed in the units of t CE^{-1} USD 10,000 GDP, calculated as:

$$CI = CF/Y \tag{5}$$

where CF is total agricultural carbon emissions (t CE), and *Y* represents total agricultural output (USD 10,000 GDP).

In contrast, carbon efficiency (CFE, also expressed per USD 10,000 GDP^{-1} t CE) refers to the ratio of agricultural production (i.e., sum of the crop plus livestock and poultry industries) to agricultural carbon emissions, calculated as:

$$CFE = Y/CF. \tag{6}$$

Decoupling theory

The decoupling elasticity concept (Tapio 2005) was based on the OECD's carbon decoupling model (OECD 2002). The latter is also known as carbon emissions elasticity, namely the ratio of the magnitude of changes in economic development to the magnitude of changes in CO_2 emissions. Compared to OECD decoupling theory, elastic decoupling theory can more accurately reflect the sensitivity of CO_2 changes to economic changes. Detailed Tapio elastic decoupling indices are shown in Table 5. In this study, we used the Tapio model for decoupling analysis of Hunan's total agricultural carbon emissions from the crop industry, the livestock and poultry industry, and their individual economic outputs (USD 10,000 GDP, with 1997 as the base year), separately. The decoupling model was constructed as follows:

$$t = \frac{\Delta C/C}{\Delta G/G} \tag{7}$$

where t represents decoupling elasticity, C represents agricultural carbon emissions, and ΔG is industrial GDP.

Statistical analysis

This study involved an analysis of carbon emissions over a 15-year time frame. The problem of multi-collinearity among repeated measurements that exists in time series can be solved by using approaches such as ridge regression and multiple linear regression analysis (MRA) (Mason and Perrault 1991; Grapentine 1997; Zhang et al. 2014). MRA minimizes the observed value and estimated difference with the least squares method, so as to fit linear equations to observed responses (Braun et al. 2014); the recommended correlation coefficient between each independent variable is less than 0.7 (Anderson et al. 2003).

In our approach, PCA was first used to filter all influencing factors that affect agricultural carbon emissions in order to determine the most significant independent variables (i.e., driving factors). We then selected variables from the PCA with high loading as the main components to build the final regression model (Abdul-Wahaba et al. 2005; Al-Alawi et al. 2008) that determined the linear relationship between agricultural carbon emissions and their drivers.

Data sources and processing

Overall, the combination of crop and livestock production is though to represent a balanced approach to economic development in the agriculture sector (China Statistical Yearbook 2013). Relying on agricultural inputs, this sector in Hunan produced a sustained, high investment yield in recent years and showed a huge potential for reduction of emissions. As our aim was to evaluate the sustainability of that approach, in terms of carbon emissions, data sources were selected in order to capture as fully as possible the range of production in this major agricultural province of China.

Data were collected from the following sources: the China Statistical Yearbook, China Rural Statistical Yearbook, China 60 Years of Agricultural Statistics, Hunan Statistical Yearbook, Hunan Rural Statistical Yearbook.

To "process" (i.e., inspect, correct, and standardize) the data, we conducted a check among all the sources to compare the same type of data reported in different sources and made any necessary adjustments during proofreading. For example, to inspect the data on application of nitrogen fertilizer, we first calculated the sum of N applied in various regions of Hunan. Then, that sum of regional data was compared with the value for the whole province, to see whether the numbers made sense. If an error was found during this step of data checking, we adjusted the value in question according to the relative proportion of the overall available data for that variable. Because the values for some agricultural material inputs raw application were lacking for 2003, instead we took the average value of the sum in 2002 and 2004.

All data analyses were performed with SPSS software, version 20.0.

Table 5 Classification of Tapio decoupling indices

	State	Environmental pressure	Economic growth	Elasticity value t
Negative decoupling	Expansionary negative decoupling	+	+	$t \geq 1.2$
	Strong negative decoupling	+	−	$t < 0$
	Weak negative decoupling	−	−	$0 < t < 0.8$
Decoupling	Strong decoupling	−	+	$t < 0$
	Weak decoupling	+	+	$0 < t < 0.8$
	Recession decoupling	−	−	$t \geq 1.2$
Connection	Expansionary connection	+	+	0.8an <1.2
	Recession connection	−	−	0.8es <1.2

Results and analysis

Total agricultural carbon emissions

The total agricultural carbon emissions in Hunan showed an overall upward trend over time; the value of 7168.89×10^4 t CE in 2012 was 1147.42×10^4 t CE (19.06 %) higher than the total in 1998. The growth rate of carbon emissions from agricultural material inputs was the highest, at 52.17 %, with an increase of 235.93×10^4 t CE (Table 6). The pattern of variation in Hunan's agricultural carbon emissions had four clear stages: slow growth, rapid growth, rapid decline, and finally a slow increase. Specifically, 1998–2002 was a period of slow growth in emissions; compared to 1998, the total in 2002 increased by only 66.06×10^4 t CE (1.10 %). The growth rate of emissions from enteric fermentation was the highest during that time, at 5.48 %, and that of agricultural material inputs was the second highest at 4.06 %. From 2002 to 2007, carbon emissions demonstrated a rapid growth phase, with an increase of 1084.42×10^4 t CE (17.81 %). Due to national policies, crop and livestock husbandry then expanded rapidly, leading to increased carbon emissions, with CH_4 emissions from rice paddies being the largest contributor. As the "three agriculture-related issues" emerged—i.e., agriculture, rural areas, and farmers—farmers were overburdened, and the investment in agricultural materials slowed down, yet the growth rate of emissions from agricultural material inputs was still 13.73 %. From 2007 to 2008, there was a rapid decline in carbon emissions; in 2008 they decreased by 374.16×10^4 t CE (5.22 %), due to a massive snowfall, but the growth rate of those from agricultural material inputs increased by 0.32 %. This shows that carbon emissions from agricultural material inputs are more important in carbon emissions from agricultural production in Hunan. From 2008 to 2012, there was a slow increase in carbon emissions; compared to 2007, because of increased government support for agriculture, production recovered rapidly and developed further, so the amount of agricultural inputs continued to rise. Total agricultural carbon emissions in 2012 increased by 371.10×10^4 t CE (5.46 %) compared to 2008, while the growth rate for emissions from agricultural material inputs increased by 28.17 % (Fig. 2).

Government implementation of a series of energy saving policies and technologies then reduced the intensity of agricultural carbon emissions (CI), year after year (Fig. 3), whereas the efficiency (CFE) gradually increased. However, due to drought conditions in 2012, the development direction of both agricultural CI and CFE was reversed. The agricultural production system in Hunan is sensitive and vulnerable, so it depends heavily on agricultural materials, showing characteristics of "high input, high pollution and high emissions" (i.e., the "three high" characteristics), weak adaptability to climate change, and unstable agricultural carbon emissions. The coupling effect that ties agricultural carbon emissions with economic development and climate change is strong, and creates a negative feedback cycle from years of accumulated climate damage caused by carbon-intensive agriculture. Taking into account population growth and food security strategies, Hunan agricultural carbon emissions will continue to rise. In this study, most of the carbon emission measures were based on domestic experimental data—the calculation boundaries for what was considered as agricultural emissions were determined scientifically, and the calculation method was feasible, so the calculation results can be considered objective and reliable.

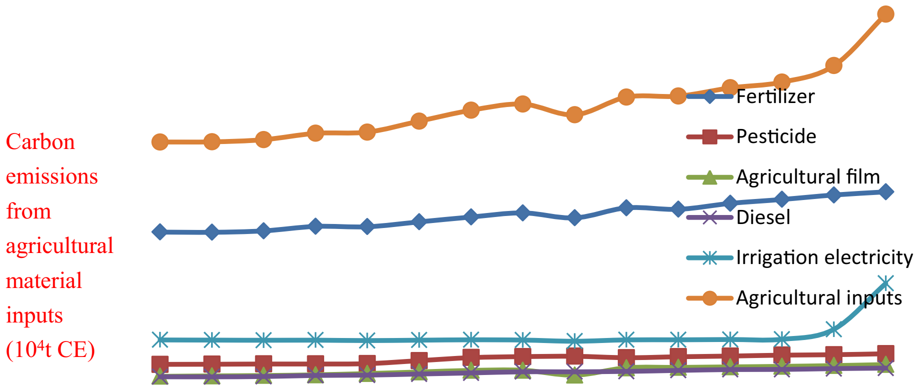
Decoupling analysis

The relationship between GHG emissions and the output value of Hunan agricultural production demonstrated mainly weak decoupling, but it was unstable. For example, the snowstorm in 2008 caused a strong decoupling state. The elastic characteristic of total agricultural carbon emissions in 2003 showed expansionary negative decoupling, which was mainly due to the negative decoupling state of crop industry expansion in 2003 along with the expansionary connection of the livestock and poultry industry in 2003. The analysis of decoupling states (Table 7) showed that agricultural emissions grew faster than did agricultural output and production. Production depended on a large number of agricultural material inputs to improve economic efficiency, and this trend eased after 2003. Because of the impact of the "three agriculture-related issues" issues, farmers' demand for production materials gradually slowed down, which inhibited the rapid growth of agricultural carbon emissions in recent decades. However, it is worth noting that drought in 2012 caused the total agricultural carbon emissions to exhibit expansionary negative decoupling, the elastic characteristics of crop carbon emissions to exhibit expansionary negative decoupling, and livestock and poultry carbon emissions to exhibit expansionary connection—these patterns suggest that Hunan agricultural production has weak adaptability to climate variation. That is, Hunan agriculture is susceptible to suffering from the impact of climate and environmental and economic policy, and other external environmental factors. The decoupling state in the livestock and poultry industry was more unstable than in the crop industry, indicating that carbon emissions from the former grew faster than the output. That in turn induced greater pressure

Table 6 Variation of agricultural carbon emissions in Hunan from 1998 to 2012 (units = 10^4 t CE)

Year	Land use			Crop production			Livestock and poultry industry production				Total agricultural C emissions
	C emissions from agricultural inputs	Total C emissions from land use	Percentage of total agricultural emissions	CH4 emissions from rice paddies	C emissions from crop production	Percentage of total agricultural emissions	C emissions from enteric fermentation carbon emission	Manure management carbon emission	Livestock and poultry industry	Percentage of total agricultural emissions	
1998	452.18	454.66	7.55	2907.77	3511.29	58.31	772.91	1282.60	2055.51	34.14	6021.47
1999	452.50	455.01	7.50	2959.77	3573.59	58.87	776.09	1265.37	2041.45	33.63	6070.05
2000	456.51	459.01	7.49	2937.12	3556.69	58.06	793.76	1316.00	2109.76	34.44	6125.46
2001	468.22	470.69	7.75	2882.00	3490.78	57.47	804.49	1308.47	2112.96	34.78	6074.43
2002	470.54	472.97	7.77	2879.02	3478.93	57.15	815.23	1320.40	2135.63	35.08	6087.53
2003	490.68	493.20	7.63	3030.63	3663.92	56.67	870.91	1437.01	2307.91	35.70	6465.03
2004	510.82	513.43	7.50	3182.24	3848.90	56.25	926.58	1553.62	2480.20	36.25	6842.53
2005	522.21	524.87	7.56	3283.43	3930.75	56.59	864.01	1626.35	2490.36	35.85	6945.97
2006	502.44	505.11	7.11	3320.90	3976.71	55.97	949.10	1673.73	2622.83	36.92	7104.65
2007	535.16	537.83	7.50	3315.45	3974.26	55.41	944.53	1715.33	2659.86	37.09	7171.95
2008	536.89	539.37	7.93	3275.86	3931.87	57.84	852.60	1473.95	2326.55	34.23	6797.79
2009	552.18	554.87	7.97	3337.72	4040.34	58.06	784.17	1580.06	2364.23	33.97	6959.44
2010	562.76	565.52	8.19	3334.83	4004.22	57.98	782.40	1553.81	2336.21	33.83	6905.95
2011	593.19	595.92	8.61	3243.91	3927.25	56.72	805.76	1594.55	2400.31	34.67	6923.49
2012	688.11	690.91	9.64	3269.58	3975.84	55.46	845.84	1656.29	2502.14	34.90	7168.89
average growth rate	3.13 %	3.12 %		0.87 %	0.92 %		0.80 %	2.00 %	1.53 %		1.29 %

Fig. 2 Carbon emissions from agricultural materials in Hunan during the period 1998–2012



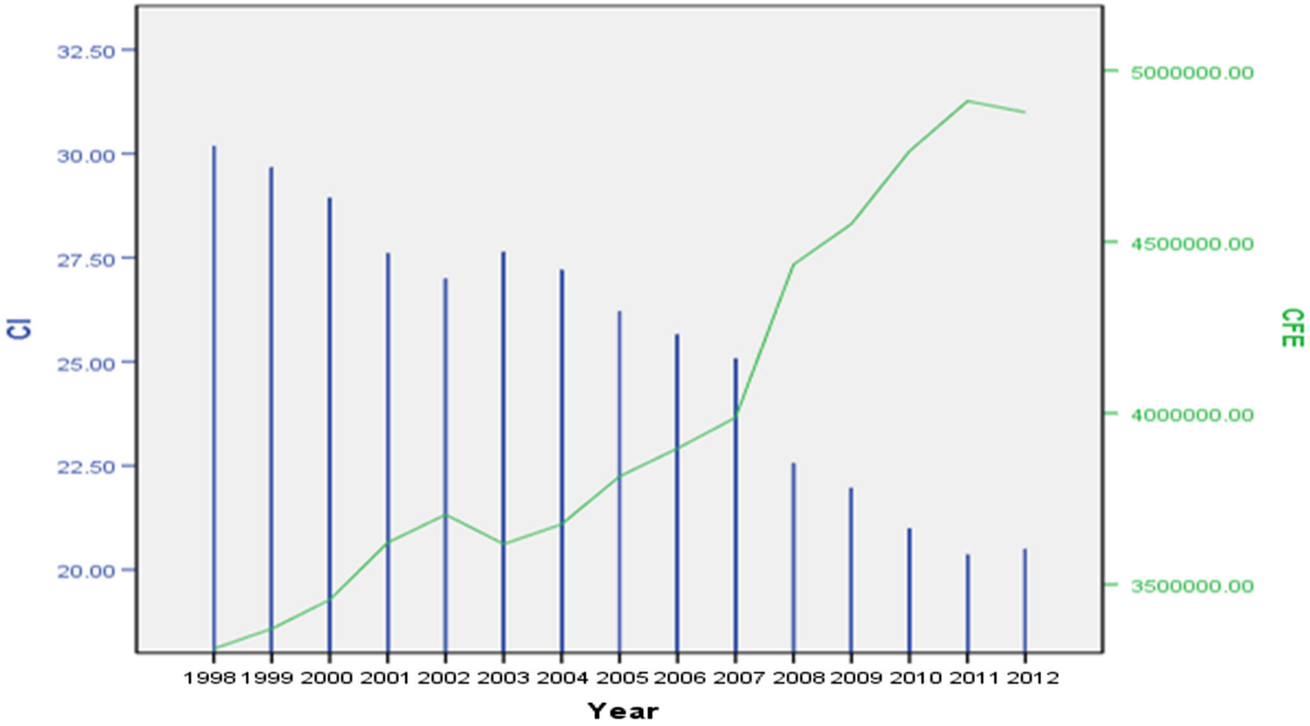


Fig. 3 Agricultural carbon intensity (CI) and carbon efficiency (CFE) in Hunan from 1998 to 2012

for reduction of carbon emissions produced by the livestock and poultry industry.

Principal component analysis of carbon emissions from crops versus livestock

Previous studies have suggested that the key variables that influence carbon emissions are economic, structural, efficiency, and demographic factors (Bennetzena et al. 2012; Dong et al. 2013; Li et al. 2011). Based on Hunan's agricultural production process and characteristics, we chose 11 kinds of indices to represent the factors that influence carbon emissions from the crop industry. These included economic factors (per capita annual net income, PI; per capita agricultural GDP, or PAG), structural factors (ratio of crop production GDP to total agricultural GDP, or CRA; ratio of rice production to total crop production, RRP), efficiency factors (crops productivity per capita, PCP; rice productivity per capita, RCP; crop arable productivity, CAP), energy input factors (amount of nitrogen fertilizer applied per acre, NAA; total power of agricultural machinery per capita, PCM), and social development factors (urbanization rate, UR; labor force, LF). For the livestock and poultry industry, we chose nine kinds of indices to represent the factors that influence carbon emissions, including economic factors (PI; PAG; household livestock income, FLI), structural factors (ratio of pork production to livestock production, PRL; ratio of beef

Table 7 Decoupling relationship between agricultural carbon emissions and their output values in Hunan from 1998 to 2012

Period	$\Delta C_P/C_P$	$\Delta G_p/G_p$	T	Carbon emission state of crop industry	$\Delta C_L/C_L$	$\Delta G_l/G_l$	T	Carbon emission state of livestock and poultry industry	$\Delta C_a/C_a$	$\Delta G_a/G_a$	t	Carbon emission state of total agriculture
1998–1999	0.016	0.049	0.322	Weak decoupling	−0.007	0.035	−0.195	Strong decoupling	0.008	0.027	0.295	Weak decoupling
1999–2000	−0.003	0.033	−0.097	Strong decoupling	0.033	0.001	34.629	Expansionary negative decoupling	0.009	0.034	0.264	Weak decoupling
2000–2001	−0.014	0.035	−0.386	Strong decoupling	0.002	0.045	0.034	Weak decoupling	−0.008	0.039	−0.213	Strong decoupling
2001–2002	−0.002	0.002	−1.208	Strong decoupling	0.011	0.051	0.210	Weak decoupling	0.002	0.023	0.092	Weak decoupling
2002–2003	0.052	0.005	10.386	Expansionary negative decoupling	0.081	0.073	1.105	Expansionary connection	0.058	0.036	1.643	Expansionary negative decoupling
2003–2004	0.049	0.094	0.525	Weak decoupling	0.075	0.056	1.333	Expansionary negative decoupling	0.055	0.076	0.723	Weak decoupling
2004–2005	0.021	0.045	0.475	Weak decoupling	0.004	0.063	0.065	Weak decoupling	0.015	0.053	0.280	Weak decoupling
2005–2006	0.006	0.055	0.107	Weak decoupling	0.053	0.034	1.565	Expansionary negative decoupling	0.022	0.045	0.493	Weak decoupling
2006–2007	0.007	0.043	0.157	Weak decoupling	0.014	0.022	0.642	Weak decoupling	0.009	0.033	0.281	Weak decoupling
2007–2008	−0.009	0.021	−0.431	Strong decoupling	−0.125	0.090	−1.392	Strong decoupling	−0.055	0.052	−1.057	Strong decoupling
2008–2009	0.028	0.059	0.470	Weak decoupling	0.016	0.043	0.377	Weak decoupling	0.023	0.052	0.451	Weak decoupling
2009–2010	−0.006	0.043	−0.129	Strong decoupling	−0.012	0.034	−0.349	Strong decoupling	−0.008	0.039	−0.199	Strong decoupling
2010–2011	−0.010	0.069	−0.148	Strong decoupling	0.027	−0.004	−6.859	Strong negative decoupling	0.003	0.035	0.072	Weak decoupling
2011–2012	0.032	0.012	2.645	Expansionary negative decoupling	0.042	0.047	0.903	Expansionary connection	0.034	0.028	1.244	Expansionary negative decoupling

C_P, C_L, and C_a denote carbon emissions from crop production, the livestock and poultry industry, and total agriculture, respectively; ΔG_P, ΔG_L, and ΔG_a represent crop industry GDP, livestock and poultry industry GDP, and total agricultural GDP production to livestock production, BRL; ratio of animal husbandry GDP to total agricultural GDP, or LRA), efficiency factors (farmland productivity in the livestock industry, LP), and social development factors (UR and LF). Results of the PCA that was used to assess all of these factors are presented in Tables 8, 9, 10, 11, 12.

The KMO values of 0.738 and 0.651 (Table 8) indicate a moderate degree of common variables, and therefore that more variables should be taken into consideration for PCA. Bartlett's sphericity test was significant, indicating clear structural property and interdependence between the original variables, and hence that factor analysis was suitable. The factors with a characteristic value >1 were extracted, and the explained variables are shown in Table 9. The first two factors had characteristic values of 92.51 and 86.27 % of the total characteristic value, so they were extracted as the main factors. The top two most relevant factors in the crop industry were UR and NAA (Tables 11,12), while in the livestock and poultry industry they were PAG and BRL, all of which were kept as substitution variables.

Table 8 KMO and Bartlett's Bartle

	Crop industry carbon emissions	Livestock and poultry industry carbon emissions
Kaiser–Meyer–Olkin measure of sampling adequacy	0.738	0.651
Bartlett's test of sphericity		
Approx. Chi-square	379.511	196.278
df	55	36
Sig.	0	0

Regression analysis of carbon emissions from crops and from livestock and poultry

The main factors from the PCA for crops (UR and NAA) and the livestock and poultry industry (PAG and BRL) were employed as independent variables for the multiple regression analysis of the dependent variable (i.e., farming industry carbon emissions and livestock–poultry industry carbon emissions), results of which are shown in Tables 13, 14, 15, 16, 17.

The correlation coefficients between the independent variables were small in the two regression analyses, and there was no multicollinearity of variables (Table 13). There was a high degree of fit in the regression ($R^2 = 0.829, 0.945$), and the model residuals did not show auto-correlation (D–W values $= 1.523, 1.747$), suggesting good performance of the regression model (Tables 14,15).

The regression coefficients of NAA and UR were 5193.164 and 8288.964 (Tables 16, 17, 18, 19), and they were significant ($P < 0.05$). Thus, for crop industry carbon emissions (C_p), the two main factors (UR $= x_1$, NAA $= x_2$,) explained nearly 93 % of the information provided by all 11 indices. The regression equation was:

$$C_p = 906.823 + 8288.964X_1 + 5193.164X_2 \tag{8}$$

Further, the coefficients of BRL and PAG were 32,934.198 and 0.354, and they were also significant ($P < 0.05$). Therefore, for livestock and poultry industry carbon emissions (C_l), the two main factors (BRL $= x_1$, PAG $= x_2$) explained nearly 87 % of the information provided by all nine indices. The regression equation was:

$$C_l = 402.834 + 32934.198X_1 + 0.354X_2. \tag{9}$$

Table 9 Ttotal explained variance of crop industry carbon emissions

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	9.146	83.147	83.147	9.146	83.147	83.147	5.947	54.059	54.059
2	1.041	9.46	92.606	1.041	9.46	92.606	4.24	38.547	92.606
3	0.382	3.477	96.083						
4	0.324	2.949	99.032						
5	0.053	0.482	99.515						
6	0.04	0.366	99.88						
7	0.008	0.071	99.951						
8	0.003	0.028	99.979						
9	0.002	0.016	99.995						
10	0	0.004	99.999						
11	9.55E−05	0.001	100						

Table 10 Total explained variance of livestock and poultry industry carbon emissions

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	5.785	64.277	64.277	5.785	64.277	64.277	5.752	63.915	63.915
2	1.979	21.988	86.265	1.979	21.988	86.265	2.012	22.351	86.265
3	0.898	9.977	96.242						
4	0.18	2.004	98.246						
5	0.07	0.779	99.025						
6	0.037	0.414	99.44						
7	0.036	0.403	99.843						
8	0.012	0.136	99.979						
9	0.002	0.021	100						

Table 11 Rotated component matrix of carbon emissions from the crop industry

	Component	
	1	2
CRA	−0.81	−0.393
RCP	0.363	0.854
LF	−0.785	−0.588
PCP	0.803	0.586
NAA	0.143	0.906
PCM	0.778	0.615
RRP	−0.963	−0.121
CAP	0.633	0.748
PI	0.677	0.654
UR	0.936	0.302
PAG	0.782	0.613

Table 12 Rotated component matrix of carbon emissions from the livestock and poultry industry

	Component	
	1	2
LF	−0.975	0.017
PAG	0.982	−0.145
UR	0.946	0.088
PRL	−0.527	−0.812
PI	0.914	−0.357
BRL	−0.129	0.956
LRA	−0.283	0.443
LP	0.92	0.128
FLI	0.942	−0.261

Discussion

Carbon emissions from the crop industry

The Chinese Government has promised to reduce carbon intensity per unit GDP by 40–50 % (versus the 2005 base year) by 2020. In 2005, the CI in Hunan Province was 26.21 t CE/USD 10,000 GDP for agriculture, 32.85 t CE/USD 10,000 GDP for the crop industry, and 19.25 t CE/USD 10,000 GDP for the livestock and poultry industry. However, the average annual decrease was only 3.40, 3.45, and 3.28 % in 2005–2012, respectively. Under the combined effects of both external environmental factors (e.g., natural resource shortages, frequent climate disasters) and socioeconomic factors (e.g., accelerating urbanization, population growth), it will be very difficult to meet the minimum requirements for emission reduction. Thus, China should take measures to promote the development of agriculture that minimize pressures on the environment (Zhang and Cheng 2009).

As urbanization in China has gradually accelerated, negative impacts on the development of agricultural production have become more prominent. Indeed, urbanization is significantly affecting China’s total carbon emissions (Lin and Liu 2010). Specifically, with a hypothetical increase in the rate of urbanization by 1 %, carbon emissions from Hunan’s crop industry will increase by 83 units. While the phenomenon of urbanization is reducing the agricultural labor force, it is also increasing land competition between urban expansion and agricultural production, placing great pressure on the supply of arable land needed to ensure food security. Efforts to ensure agricultural productivity, despite labor shortages and the lack of arable land, will inevitably lead to sustained high levels of agricultural investment in fossil fuels, which has already created a series of climate and other environmental problems. Thus, the protection of prime agricultural land has become a critical measure for the simultaneous development of agricultural production and reduction of agricultural emissions.

Our findings indicated that carbon emissions from the use of nitrogen fertilizers accounted for 51.48 % of the total carbon emissions due to agricultural material inputs—

Table 13 Pearson correlation matrix for main factors used in multiple regression

	NAR	UR		BRL	PAG
NAR	1	0.409	BRL	1	−0.275
UR	0.409	1	PAG	−0.275	1

much less than what has been reported for nitrogen fertilizers in the British crop industry (75 %, Hillier et al. 2009), though not much different than measures for nitrogen fertilizers in the total Chinese crop industry (52.5–56.5 %), (Cheng 2011). The discrepancy compared to the UK might be due to the underdeveloped economy of Hunan Province (which is about average when compared to all provinces of China). Carbon-intensive agriculture has become China's major development model for agricultural production. The carbon intensity of Hunan's crop industry depends significantly on the use of nitrogen fertilizers (Fig. 4a). In China as a whole, many chemical fertilizers are used in agricultural production though the seasonal utilization rate is low, reportedly 30–35 % for nitrogen, 35–50 % for potash, and 15–20 % for phosphate (Wang et al. 2010). In

Table 14 Statistical performance indicators for different models[a] of crop industry carbon emissions

Model	R	R^2	Adjusted R^2	Std. error of the estimate	Durbin–Watson
1	0.847[a]	0.717	0.695	147.527	
2	0.911[b]	0.829	0.801	119.217	1.523

[a] Dependent variable: farming carbon emissions

[b] Predictors: (constant), urbanization rate

[c] Predictors: (constant), urbanization rate, amount of nitrogen fertilizer applied per acre

Table 15 Statistical performance indicators for different models[a] of livestock and poultry industry's carbon emissions

Model	R	R^2	Adjusted R^2	Std. error of the estimate	Durbin–Watson value
1	0.676[b]	0.457	0.415	154.43768	
2	0.972[c]	0.945	0.936	51.17634	1.747

[a] Dependent variable: livestock and poultry industry carbon emissions

[b] Predictors: (constant), per capita agricultural GDP

[c] Predictors:(constant), per capita agricultural GDP, ratio of beef production to animal husbandry production

Table 16 Coefficients of crop production for carbon emission model 1

Model 1	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	1912.541	420.570		4.547	0.001
Urbanization rate	10,081.572	1757.911	0.847	5.735	0.000

Table 17 Coefficients of livestock and poultry industry for carbon emission model 1

Model 1	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	1569.363	233.270		6.728	0.000
Per capita agricultural GDP	0.273	0.082	0.676	3.308	0.006

Table 18 Coefficients of crop production for carbon emission model 2

Model 2	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	906.823	493.384		1.838	.091
Urbanization rate	8288.964	1557.061	.696	5.323	.000
Amount of nitrogen fertilizer applied per acre	5193.164	1846.818	.368	2.812	.016

Table 19 Coefficients of livestock and poultry industry carbon emission model 2

Model 2	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	402.834	136.988		2.941	0.012
Per capita agricultural GDP	0.354	0.028	0.876	12.436	0.000
Ratio of beef production to livestock production	32,934.198	3192.998	0.727	10.315	0.000

contrast, the utilization rate in developed countries can reach ~60 % (Janzen et al. 2003). Improving the utilization efficiency of nitrogen fertilizers is thus an important means for developing agriculture in China while reducing carbon emissions from crop production, especially those from nitrogen fertilizers.

Overall, our results were similar to other assessments of carbon emissions from the Chinese agriculture sector. A study of the carbon footprint of China's agricultural production from 2002 to 2011 (Tian et al. 2014), including crops, livestock, and poultry, found that those carbon emissions in 2002, 2005, 2008, and 2011 were 4934.37 wtCE, 5333.18 wtCE, 5329.33 wtCE, and 5622.68 wtCE, respectively, in Hubei. That province is close to Hunan and has similar characteristics of agricultural production. They calculated that agricultural emissions for those years in Hunan were 5944.57 wtCE, 6695.69 wtCE, 6500.81 wtCE, and 6737.26 wtCE. Those estimates were similar to our findings of 6087.53 wt, 6945.97 wt, 6797.79 wtCE, and 6923.49 wtCE. The discrepancy could be due to variation in the method of calculation, the carbon emission coefficient that we used for nitrogen fertilizers, and the fact that our study included emissions from straw burning.

In China, every 1 % increase in the rate of fertilizer efficiency can avoid the use of ~2.5Mt of standard coal (Chen and Zhang 2010). Theoretically, if the amount of nitrogen applied per acre were reduced by 10 %, carbon emissions from crop production in Hunan would be reduced by 519 units. The improvement of nitrogen fertilizer efficiency in crop production is strongly encouraged in the practice of agriculture, via the use of both organic and inorganic fertilizers, controlled release nitrogen fertilizer and imitation release fertilizers, scientific water management, and other measures, thereby reducing the amount of fertilizer needed. In the red soil paddy fields where double cropping of rice occurs, the combined application of organic and inorganic fertilizers can increase production by 30 % and the amount of carbon sinks by 50 %, compared to the application of solely chemical fertilizers (Li et al. 2009).

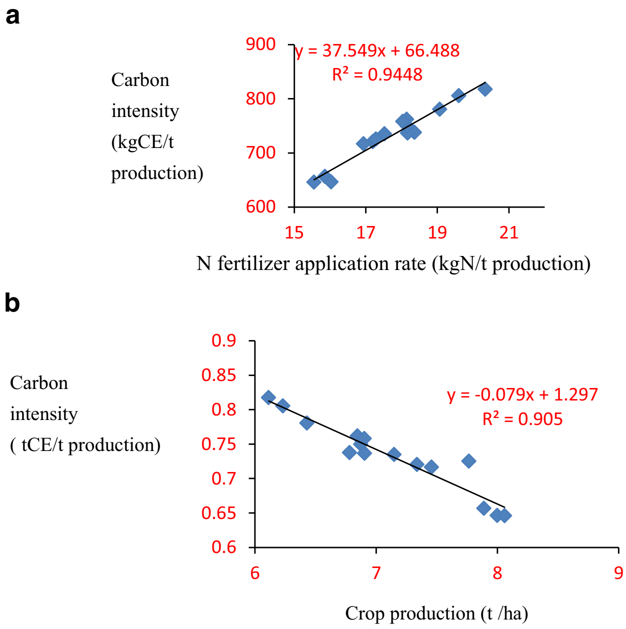


Fig. 4 **a** Correlation between total CF of crop production and annual *N* fertilizer application rate in crop production, **b** correlation between crop production capacity and carbon intensity of production

We found a negative linear correlation between crop productivity and the carbon intensity per yield, suggesting that increasing carbon intensity could not bring about an increase in crop production (Fig. 4b). But the trend for the use of excessive chemical fertilizers and other agricultural materials has been increasing recently in China's agricultural production (Zhang et al. 2008). Considering the diminishing rates of return from chemical fertilizers along with their side effects on soils, the net amount of fossil energy required will increase in the foreseeable future. This trend adds more pressure for mitigating the environmental impact of crop production practices. In the study of agricultural carbon emissions and the development of policies to reduce them, it is essential to correctly recognize and understand the negative correlation between agricultural production and carbon emissions from agricultural material inputs.

Carbon emissions from the livestock and poultry industry

The emissions of CH_4 and N_2O from livestock production come mainly from animal gastrointestinal fermentation and manure management; the amount of emissions depends on how livestock are fed, manure handling, and the environment in which they are housed. CH_4 emissions from livestock gastrointestinal fermentation account for one third of global agricultural non-CO_2 emissions (USEPA 2006). Using the IPCC method to calculate GHG emissions from China's livestock and poultry industry during 2000–2007, Hu and Wang (2010) found that ruminants caused the most CH_4 emissions from gastrointestinal fermentation, while the major sources of CH_4 and N_2O from livestock feces were pigs and poultry. The 2011 emissions of CH_4 and N_2O from animal husbandry were 1041.81 and 40.87×10^4 tons, respectively, with gastrointestinal fermentation and manure management contributing most (Chen and Shang 2014). Thus, we used the measures of PRL and BRL to assess livestock and poultry industry GHG emissions. We found that in Hunan Province, carbon emissions from cattle and pig rearing accounted for 39 and 48 % of total carbon emissions from the livestock industry, and that there was a negative correlation between carbon emissions from those industries versus the pork production ratio. Interestingly, the beef ratio was one of the main factors that influenced emissions from the livestock and poultry industry (Fig. 5). The reason may be that CH_4 produced by ruminant gastrointestinal fermentation is the main source of GHG in that industry, and the CH_4 and N_2O emission factor for ruminants is far greater than that of pigs. De Vries and de Boer (2010) calculated the carbon emissions per kg of yield for a variety of livestock and poultry in Europe; for example, they were 15–32 kg CE for beef, 4–11 kg CE for pork, and 4–6 kg CE for chicken. That suggested a huge potential for emission reductions in the rearing of ruminants, similar to our results in this study. Regression analysis showed that if the BRL declined by 1 %, livestock GHG emissions would decline by 329 units.

Per capita GDP is recognized as one of the key factors that influence the growth in total global carbon emissions (Tucker 1995; Taskin and Zaim 2000; Neumayer 2002; RauPach et al. 2007; Wagner 2008). Chen and Shang (2014) confirmed that economic factors are the greatest incentive for livestock industry GHG emissions in China. Here, we showed that if agricultural GDP per capita were to increase by one unit, the livestock and poultry industry's GHG emissions would increase by 0.354 units. Presumably, economic development factors will remain as the main inducement for increased carbon emissions from livestock and poultry in developing countries, over the long term.

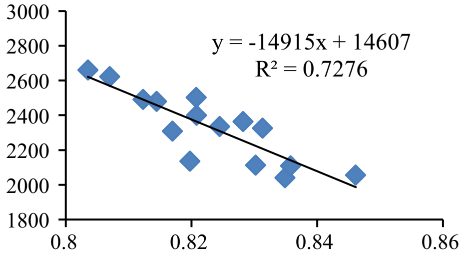


Fig. 5 Correlation between carbon emissions from the livestock and poultry industry and the ratio of pig production to total animal production

The livestock and poultry industry produces a large amount of carbon emissions, and the demand for the yield and quality of livestock products is steadily rising, so it will be very difficult to reduce GHG emissions from this source, in general. The trend of livestock development lies in large-scale and intensive development, which will bring more favorable conditions for the improvement of livestock quality, diet, disease prevention and control, waste treatment, and other technical aspects.

Thus, in Hunan, across China, and abroad, innovation of crop production technology and improvement of the quality of employees will not only promote unit productivity of the livestock and poultry industry, but will also reduce carbon emissions. Hermansen and Kristensen (2011) argued that, in addition to focusing on livestock manure management to reduce emissions, attention must also be paid to the utilization efficiency of manure as inorganic fertilizers in the crop industry, along with the development of bio-energy applications. In developing countries, this would be an effective measure to reduce emissions from livestock and poultry production, and to strengthen the agriculture industry through research and development of efficient bio-energy sources from livestock manure (e.g., methane).

Conclusion

Our findings show that among carbon emissions from Hunan's agriculture sector, material inputs were the component with the highest growth rate, at 52.17 %. That source accounted for 50.79 % of total growth in carbon emissions from the province's crop production during 1998–2012. To a certain extent, emissions from crop production were positively correlated with the utilization rate of nitrogen fertilizer, and crop productivity was linearly and negatively correlated with carbon intensity per yield. That suggested that continually increasing the amount of agricultural material inputs does not lead to a proportional increase of agricultural productivity. We cautioned that agricultural production and the development of policies to reduce agricultural emissions depend on an accurate understanding of the correlation between agricultural production and carbon emissions. Most importantly, they depend on finding the optimal economic combination of agricultural production and reduction in agricultural emissions. There was a weak state of decoupling between Hunan agricultural carbon emissions and their output value, but the decoupling was unstable. Priorities for mitigation should be improving the utilization efficiency of nitrogen fertilizers, protecting farmland to reduce emissions, and developing the crop industry in Hunan. Optimizing the production structure and enhancing low-carbon production methods and the scale of operation in order to improve productivity in the livestock and poultry industry will be key tasks for achieving emissions reduction and the sound development of Hunan's livestock industry.

Compliance with ethical standards

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

References

Abdul-Wahaba SA, Bakheitb CS, Al-Alawi SM (2005) Principal component and multiple regression analysis in modelling of ground-level ozone and factors affecting its concentrations. Environ Model Softw 20:1263–1271

Al-Alawi SM, Abdul-Wahab SA, Bakheit CS (2008) Combining principal component regression and artificial neural networks for more accurate predictions of ground-level ozone. Environ Model Softw 23:396–403

Anderson DR, Sweeney DJ, Williams TA (2003) Modern business statistics with microsoft excel. Cengage Learning, Boston

Bennetzena BH, Smith P, Soussanac JF, Portera JR (2012) Identity-based estimation of greenhouse gas emissions from crop production: case study from Denmark. Eur J Agron 41:66–72

BP China (2007) Calculator of carbon emissions. http://www.bp.com/sectiongenericarticle.do?categoryId=9011336&contented=7025421

Braun MR, Altan H, Beck SBM (2014) Using regression analysis to predict the future energy consumption of a supermarket in the UK. Appl Energy 130:305–313

Cao GL, Zhang XY, Wang YQ et al (2007) Estimation of China's regional straw open burning emissions. Chin Sci Bull 15:1826–1831

Chen Y, Shang J (2014) Disconnect analysis and influence factors of animal husbandry in China. China Popul Resour Environ 24(3):101–107

Chen GQ, Zhang B (2010) Greenhouse gas emissions in China 2007: inventory and input-output analysis. Energy Policy 38:6180–6193

Cheng K, Pan GX, Smith P et al (2011) Carbon footprint of China's crop production: an estimation using agro-statistics data over 1993–2007. Agric Ecosyst Environ 142:231–237

De Vries M, de Boer IJM (2010) Comparing environmental impacts for livestock products: a review of life cycle assessments. Livest Sci 128:1–11

Dong G, Mao XQ, Zhou J, Zeng A (2013) Carbon footprint accounting and dynamics and the driving forces of agricultural production in Zhejiang Province, China. Ecol Econ 91:38–47

Dubey A, Lal R (2009) Carbon footprint and sustainability of agricultural production systems in Punjab, India, and Ohio, USA. J Crop Improve 23:332–350

FAO (2009) Food security and agricultural mitigation in developing countries: options for capturing synergies. http://www.fao.org/docrep/012/i1318e/i1318e00.pdf

Grapentine A (1997) Managing multicollinearity. Mark Res 9(3): 11–21

Guivarch C, Mathy S (2012) Energy-GDP decoupling in a second best world-a case study on India. Clim Change 113:339–356

Hermansen JE, Kristensen T (2011) Management options to reduce the carbon footprint of livestock products. Anim Front 7(1):33–39

Hillier J, Hawes C, Squire G, Hilton A, Wale S, Smith P (2009) The carbon footprints of food crop production. Int J Agric Sustain 7:108–118

Hu XD, Wang JM (2010) Estimation of livestock greenhouse gases discharge in China. Trans Chin Soc Agric Eng 26(10):247–252

IPCC (2006) 2006 IPCC Guidelines for national greenhouse gas inventories, Vol 4 Agriculture, Forestry and Other Land Use. Geneva, Switzerland

Janzen HH, Beauchemin KA, Bruinsma Y et al (2003) The fate of nitrogen in agroecosystems: an illustration using Canadian estimates. Nutrient Cycling in Agroecosystems 67:85–102

Johnson JMF (2007) Agricultural opportunities to mitigate greenhouse gas emissions. Environ Pollut 150(6):107–124

Lee J, List JA (2004) Examining trends of criteria air pollutants: are the effects of government intervention transitory? Environ Resource Econ 29(1):21–37

Li JJ, Pan GX, Li LQ, Zhang XH (2009) Estimation of net carbon balance and benefits of rice-rice cropping farm of a red earth paddy under long term fertilization experiment from Jiangxi, China. J Agro-Environ Sci 28(12):2520–2525

Li B, Zhang JB, Li HP (2011) Research on spatial-temporal characteristics and affecting factors decomposition of agricultural carbon emission in China. China Popul Resour Environ 21:80–86

Lin BQ, Liu XY (2010) China's carbon dioxide emissions under the urbanization process: influence Factors and Abatement Policies. Econ study 8:66–78

Lu F, Wang XK, Han B (2008) Assessment on the availability of nitrogen fertilization in improving carbon sequestration potential of China's cropland soil. Chin J App Ecol 19(10):2239–2250 **(in Chinese with English summary)**

Mason CH, Perrault WD (1991) Collinearity, power, and interpretation of multiple regression analysis. J Mark Res 28(3):268–280

Min JS, Hu H (2012) Calculation of greenhouse gases emission from agricultural production in China. China Popul Resour Environ 22(7):21–27

Mosier AR, Duxbury JM, Frreney JR et al (1998) Mitigation agricultural emission of methane. Clim Change 40:39–80

National Development and Reform Commission of China (NDRCC) (2010) Transcript of deputy director of the committee answers to questions about energy conservation and climate change (in Chinese). http://xwzx.ndrc.gov.cn/wszb/t20100310334122.htm

NDRC (2004) The People's Republic of China initial national communications on climate change. China Planning Press, Beijing

Neumayer E (2002) Can natural factors explain any cross-country differences in carbon dioxide emissions? Energy Policy 30:7–12

OECD (2002) Indicators to measure decoupling of environmental pressure from economic growth. OECD, Paris

Pang ZJ, Wang XK, Mu YJ et al (2011) Nitrous oxide emissions from winter wheat field in the loess plateau. Acta Ecol Sinica 31(7):1896–1903

Paustian K, Vernon CC (1998) CO_2 Mitigation by agriculture: an overview. Clim Change 40:135–162

Peng H, Ji XH, Liu ZB, Shi LH, Tian FX, Li HS (2009) Evaluation of net carbon sink effect and economic benefit in double rice field ecosystem under longterm fertilization. China J Agro-Environ Sci 28(12):2526–2532 **(in Chinese with English summary)**

Qian HL, Fu WJ, Li SF, Li GX (2007) Irrigation and drainage load investigation in south grid of Hebei province. Power Demand Side Manage 9(4):77–78 **(in Chinese)**

Qiu WH, Liu JS, Hu CX et al (2010) Comparison of nitrous oxide emission from bare soil and planted vegetable soil. Ecol Environ Sci 19(12):2982–2985

Rajab JM, MatJafri MZ, Lim HS (2013) Combining multiple regression and principal component analysis for accurate predictions for column ozone in Peninsular Malaysia. Atmos Environ 71:36–42

RauPach MR, Marland G, Ciais P et al (2007) Global and regional drivers of accelerating CO_2: emissions. Proc Natl Acad Sci 104:10288–10293

Schneider UA, McCarl BA, Schmid E (2007) Agricultural sector analysis on greenhouse gas mitigation in US agriculture and forestry. Agric Syst 94:128–140

Shu YQ, Nina SNL (2011) Spatial disaggregation of carbon dioxide emissions from road traffic based on multiple linear regression model. Atmos Environ 45:634–640

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, Mc Carl B, Ogle S, O'Mara F, Rice C, Scholes B, Siretenko O (2007b) Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds), 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, United Kingdom/New York, pp498–540

Tapio P (2005) Towards a Theory of Decoupling: degrees of Decoupling in the EU and the Case of Road Traffic in Finland between 1970 and 2001. J Transp Policy 12(2):137–151

Taskin F, Zaim O (2000) Searching for a Kuznets curve in environmental efficiency using Kernel estimation. Econ Lett 68:217–223

Tian Y, Zhang JB (2013) Regional differentiation research on net carbon effect of agricultural production in China. J Nat Resour 8(20):1298–1309

Tian Y, Zhang JB, Li B (2012a) Intensities of agricultural carbon emissions and their causes in the major grain producing areas in China. Prog Geogr 31(11):1546–1551

Tian Y, Zhang JB, Li B (2012b) Agricultural carbon emissions in China: calculation, spatial-temporal comparison and decoupling effects. Resour Sci 34(11):2097–2105

Tian Y, Zhang JB, Yin CJ et al (2014) Distributional dynamics and trend evolution of China's agricultural carbon emissions An analysis on panel date of 31 provinces from 2002 to 2011. China Popul Resour Environ 24:97–98

Tucker M (1995) Carbon dioxide emissions and global GDP. Ecol Econ 15:215–223

U.S. Environmental Protection Agency [USEPA] (2006) Global anthropogenic Non-CO_2 greenhouse gas emissions: 1990–2020. USEPA,Washington, DC, USA. http://www.epa.gov/climatechange/economics/international.html. Accessed Sept 24, 2008

Verbeke T, De Clercq M (2006) The EKC: some really disturbing Monte Carlo evidence. Environ Model Softw 21(10):1447–1454

Verge XPC, De Kimpe C, Desjardins RL (2007) Agricultural production, greenhouse gas emissions and mitigation potential. Agric For Meteorol 142:255–269

Wagner M (2008) The carbon Kuznets curve: a cloudy picture emitted by bad econometrics? Resour Energy Econ 30:388–408

Wang ZP (1997) Estimation of nitrous oxide emission of farmland in China. Rural Eco-environ 13(2):51–55

Wang SB, Su WH (1993) Estimation of nitrous oxide emission and its future change in China. Environ Sci 14(3):42–46

Wang X, Li ZY, Ma WQ et al (2010) Effects of fertilization on yield increase of wheat in different agro-ecological regions of China. Scientia Agricultura Sinica 43(12):2469–2476

West TO, Marland G (2002) A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agric Ecosys Environ 91:217–232

Wu XR, Zhang JB, Tian Y et al (2014) Provincial Agricultural Carbon Emissions in China: Calculation, Performance Change and Influencing Factors. Resources Science 36(1):129–138

Xiong ZQ, Xing GX, Tsuruta H et al (2002) The effects of summer legume crop cultivation on nitrous oxide emissions from upland farmland. Sci Agric Sinica 35(9):1104–1108

Zhang XP, Cheng XM (2009) Energy consumption, carbon emissions, and economic growth in China. Ecol Econ 68(10):2706–2712

Zhang FS, Wang JQ, Zhang WF et al (2008) Nutrient use efficiencies of major cereal crops in China and measures for improvement. Acta Pedol Sinica 45(5):915–924 **(in Chinese with English summary)**

Zhang J, Wang CM, Liu L et al (2014) Investigation of carbon dioxide emission in China by primary component analysis. Sci Total Environ 472:239–247