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Carbon Functions of Agricultural Land Use and Economy across China: A Correlation Analysis

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Abstract

Release of CO_2 has caused significant climate change, and agricultural land use consitutes an important carbon source as well as principal carbon sinks. This paper, by examining carbon functions of main agricultural land in China, shows that in 2000-2008 the annual growth rate of carbon emission for arable land amounted to 2.47 percent, the average annual growth of carbon sinks for forest reached 3.19 percent, and the diminishing rate of carbon sink for grassland turned to be small but quite distinct. For arable land, higher carbon emissions are mainly located in its central provinces and major agricultural provinces, while higher carbon intensity in its eastern coastal provinces. Agricultural land of 9 provinces in China was found with net carbon emissions, primarily in the agricultural provinces and ecologically fragile urban areas, whereas the other 22 provinces with net carbon sinks. The EKC tests between carbon intensity of agricultural land and agricultural output per capita illustrate a significant inverted U-curve relationship; as for agricultural output per capita, the inflection point of 9,615 RMB yuan was surpassed by 11 provinces, mainly in eastern China, developed cities and the northeast region. Finally, policy recommendations are proposed to reduce carbon emissions of agricultural land use across China.

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Keywords: agricultural land; carbon functions; Environmental Kuznets Curve (EKC);

1. Introduction

Scientific evidence shows that in recent decades, human abuse of natural resources is becoming more serious, such as deforestation, uncontrolled use of fossil fuels, and other land-abusing activities, resulting in a significant impact as a sustained increase in atmospheric CO2 concentration, the reason of global

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warming. The functional change of agricultural land is not only an important carbon source, but also the most important carbon sinks. According to the World Resource Organization: global carbon emissions caused by land-use change accounts for 1/3 of total carbon emissions which is caused by human activities from 1850 to 1998; in China, the accumulated national carbon emissions by land-use change is 10.6PgC from 1950 to 2005, which is 30 percent of the total anthropogenic carbon emissions , accounting for 12 percent land use change carbon emissions of global over the same period. since the 1980's, due to large-scale forestation and returning farmland to forest, the level of carbon storage in terrestrial ecosystems in China has improved significantly, absorbing 1/4 to 1/3 of the anthropogenic carbon emissions over the same period, and this has been confirmed by a number of domestic Ecologists [1]. As for the significance of this study, the analysis of the agricultural structure and regional characteristics from the carbon emissions and carbon sinks, and the further analysis of the carbon emissions associated with the economic effects of agricultural land can help grasp the situation and the economic impact of carbon function, and can help adjust the agricultural land use structure to achieve emission reduction sinks.

2. Carbon functional evaluation method and data sources

2.1. Evaluation Method

Carbon functions of agricultural land use are divided into carbon emissions and carbon sequestration. In this paper, the main types of agricultural land involve three categories: farmland, woodland and grassland. Agricultural land carbon sinks mainly refers to forest, grassland natural carbon sinks. Carbon emissions mainly refer to the carbon emissions of cultivated land use. Carbon emissions in the paper mainly refer to greenhouse gas emissions resulting from chemical fertilizers, pesticides, energy consumption due to crop production process. As crops in the production process of carbon sequestration through the people's food consumption of the final will produce carbon emissions, it is difficult to make a correct estimate. Therefore, the carbon sink function of crops shall not be counted here. The carbon absorption coefficient of woodland and grassland is based on empirical data derived from the previous research.

In general, land carbon emissions are produced from four aspects: the first is the process of fertilizer production and use; the second is the process of production and use of pesticides; the third is the use of agricultural machinery; and the fourth is the indirect cost of irrigation during the formation of fossil fuel carbon release.

The formula for estimating carbon emissions:

$$E = \sum E_i = \sum T_i \cdot \delta_i \qquad (1)$$

Where E is agricultural land-use carbon emissions, Ei is the amount of carbon emissions for all types of carbon emissions, T_i is the amount of carbon emissions for carbon emission sources, δ_i and is the carbon emission coefficient. According to the empirical data, respectively, of agricultural land carbon functions sum calculated coefficients in Table 1.

Table 1 Carbon functions, coefficient and reference sources of main agricultural land

Types of agricultural land	carbon source / sink	Carbon emission factor	reference source
land carbon emissions	fertilizer	0.8956 kg·kg-1	T.o.west[2] 、 Oak Ridge National Laboratory
	pesticide	4.9341 kg·kg-1	Oak Ridge National Laboratory Pesticide 4.9341 kg • kg-1 Oak Ridge

			National Laboratory [4]
	agricultural machinery	16.47 kg·Cha^{-1}	T.o.west
	Irrigation	266.48 kg·Cha^{-1}	T.o.west
Forest carbon sinks		0.49 T（C）/hm^2	Huang Xian-jin [1]
Grassland carbon sinks		0.0021 kg（C）m^{-2}a^{-1}	Fang JY, Guo Zhao Di et al[3]

2.2 Data sources

In this study, relevant indicators and land use data are mainly based on *China Rural Statistical Yearbook,* and the data about chemical fertilizers, pesticides, agricultural machinery, irrigation area, and others are based on *China Statistical Yearbook*.

3. Analysis on carbon functional evaluation results of agricultural land in different use patterns

3.1 The carbon functional of agricultural land in different use patterns from 2000 to 2008

Table 2 showed that land-use carbon emissions growth was obvious, which increased from 6046.33 million tons to 7347.55 million tons during 2000 to 2008, the average annual growth rate being 2.47 percent. Fertilizer use for the land is the main source of carbon emissions, accounting for up to an average of 61.45 percent, followed for irrigation, use of pesticides and agricultural mechanization, the average proportion of their emissions being 23.96 percent, 10.12 percent and 4.47 percent. As for the changes in the growth index, the fastest average growth rate was carbon emissions of pesticides, to 4.71 percent, followed by fertilizer, irrigation, and finally used for agricultural mechanization, and its growth rate was 3.74 percent, 1.19 percent and 0.46 percent. With the increased carbon emissions from the cultivated land, cropland area decreased year by year, and the average carbon emissions per ha cultivated land increased 471.45 kg in 2000 to 603.60 kg in 2008, the average annual growth rate being 3.14 percent, higher than the total growth rate. Forest area had a big increase in 1999 than in 1949, and it has been showing a weak growth since 2000, which is a consistent performance with the influence of the-returning-farmland-to-forest policy.

Forest has an important carbon sink, as to achieve the aim of reducing greenhouse gas by increasing the carbon sink forest area has become a popular policy choice worldwide. Estimates found that the amount of forest carbon sinks from 112,106,600 tons in 2000 increased to 115,685,100 tons in 2008, an increase of 3.19 percent. Lawn is the second largest carbon sink. In recent years, with the development of economic construction and the growing concerns on food security, the speed of grassland area reduction is increasingly in a serious way. The State Council Development Research Centre pointed out in its *National Grassland Project Impact Assessment and Improvement of Grassland Management in 2009* that at present, the severely degraded grassland in China was nearly 180 million hectares, and 2 million hectares of grass land was degrading annually. With the reduction of grassland area and grassland degradation, grassland carbon sink gradually decreased, from 5,539,100 tons in 2000 down to 5,498,500 tons in 2008. Although the number is not big, the trend is obvious.

Overall, China's net carbon sink of agricultural land can be divided into different stages: it is in a stable phase from 2000 to 2003, then decreased dramatically in 2003-2008, suffering from 3.53 percent decrease annually.

Table 2 Carbon functional of different agricultural land use patterns in China from 2000 to 2008,

unit: million tons

year	land use carbon emissions								
	fertilizer	pesticide	agricultural machiner	irrigation can	total emissions	carbon emissions per unit area (kg / ha)	forest carbon sinks	grassland carbon sink	net carbon sequestration
2000	3713.68	631.56	266.89	1434.20	6046.33	471.45	11210.66	553.91	5718.24
2001	3809.87	629.10	266.38	1445.64	6150.99	481.95	11230.36	554.08	5633.45
2002	3886.54	646.86	265.11	1448.45	6246.96	496.05	11305.28	553.40	5611.72
2003	3951.21	653.77	261.90	1439.37	6306.25	511.05	11464.43	552.54	5710.72
2004	4152.72	683.87	264.43	1451.74	6552.76	535.20	11517.30	551.68	5516.22
2005	4268.80	720.38	268.40	1466.42	6724.00	550.80	11551.31	550.50	5377.81
2006	4413.45	758.37	263.64	1485.64	6921.10	568.35	11569.93	550.06	5198.89
2007	4574.75	800.80	266.54	1506.10	7148.19	587.25	11569.73	549.92	4971.46
2008	4692.26	824.98	272.16	1558.15	7347.55	603.60	11568.51	549.85	4770.81

3.2 Analysis on the characteristics of the carbon function in different areas

The results of the carbon function of provincial agricultural land use in 2008 (Table 3) show that, the top 10 provinces of land carbon emissions are Henan, Shandong, Jiangsu, Hebei, Anhui, Hubei, Hunan, Sichuan, Guangdong, Heilongjiang. They are mainly located in the central part of China and are major agricultural provinces. Their emissions account for 61.17 percent of total arable land. The last 10 provinces are Gansu, Guizhou, Chongqing, Hainan, Ningxia, Tianjin, Shanghai, Beijing, Qinghai, Tibet, and they are located in the western part of China while their total carbon emissions account for 7.82 percent of the country's total carbon emissions. As the carbon emission intensity is concerned, the top 10 ranked as Fujian, Guangdong, Jiangsu, Shanghai, Henan, Hubei, Beijing, Hunan, Hainan, Shandong, mainly in eastern coastal area and were major agricultural province. This pattern shows that in China's, agriculture still has the problem of high consumption, high pollution and high emissions, and there was no revolutionary change in agricultural production in China. As far as of the carbon sinks in various areas is concerned, there are large differences in regional forest carbon sequestration as different resource endowments, forest carbon sinks highest Heilongjiang (1121.27 million tons) is more than 1000 times higher than the lowest in Shanghai (1.18 million tons) . Grassland carbon sequestrations are mainly in Inner Mongolia, Tibet, Xinjiang, Qinghai, Sichuan, Gansu province, and these 6 provinces' grassland carbon sink account 94.65 percent for the country's total grassland carbon sequestration in 2008.

As far as the net carbon sink of agricultural land in various regions in 2008 in concerned, Henan, Shandong, Jiangsu, Anhui, Hebei, Hubei, Tianjin, Shanghai and Ningxia province are all the net carbon emissions. Henan is the highest net carbon emissions of 6,076,800 tons; Compared with other 22 net carbon sink provinces, Inner Mongolia is the largest net carbon sink, reaching 9.7232 million tons (see Table 3).

Table 3 Carbon functional of the main agricultural provinces in China in 2008 unit: million tons

year	land use carbon emissions								
	fertilizer	pesticide	agricultural machine	irrigation can	total emissions	carbon emissions per unit area (kg / ha)	forest carbon sinks	grassland carbon sink	net carbon sequestration
Beijing	12.18	1.91	0.58	6.44	21.11	909.90	33.66	0.0042	12.56
Tianjin	23.20	1.88	0.84	9.28	35.19	798.00	1.76	0.0021	-33.43
Hebei	279.80	41.98	16.07	121.49	459.34	727.20	216.68	1.6779	-240.98

Shanxi	92.61	11.83	6.59	33.43	144.46	356.10	216.58	1.3818	73.50
Inner Mongolia	138.02	9.44	11.80	76.51	235.77	329.85	1070.31	137.7789	972.32
Liaoning	115.36	25.88	6.49	39.78	187.51	459.00	279.25	0.7329	92.47
Jilin	146.71	20.00	8.56	44.08	219.34	396.30	453.01	2.1924	235.85
Heilongjiang	161.84	30.80	20.45	83.21	296.30	250.50	1121.27	4.6368	829.60
Shanghai	12.81	3.99	0.66	6.25	23.71	971.70	1.18	——	-22.53
Jiangsu	305.23	46.30	13.02	101.72	466.28	978.75	15.83	0.0021	-450.44
Zhejiang	83.29	32.46	4.51	38.26	158.53	825.30	275.82	——	117.30
Anhui	275.32	55.03	15.65	92.03	438.04	764.40	176.20	0.0588	-261.77
Fujian	106.31	28.37	3.86	25.46	164.01	1233.15	407.04	0.0063	243.05
Jiangxi	119.12	47.69	9.31	49.06	225.19	796.50	505.39	0.0084	280.21
Shandong	426.59	85.59	19.59	129.44	661.21	879.90	66.49	0.0714	-594.65
Henan	538.91	58.78	25.00	132.95	755.64	953.40	147.93	0.0294	-607.68
Hubei	293.50	68.30	12.52	62.10	436.42	935.70	388.91	0.0924	-47.41
Hunan	200.09	55.63	13.17	72.19	341.07	900.15	583.35	0.2184	242.48
Guangdong	202.95	49.59	7.63	49.66	309.83	1094.40	496.27	0.0567	186.50
Guangxi	199.37	30.59	9.81	40.54	280.31	664.50	568.40	1.5036	289.59
Hainan	40.84	15.99	1.40	6.56	64.79	889.95	72.57	0.0399	7.82
Chongqing	78.91	10.35	5.46	17.56	112.27	502.05	161.26	0.4977	49.48
Sichuan	217.46	29.99	16.03	66.80	330.28	555.30	964.22	28.7931	662.74
Guizhou	74.43	6.37	7.88	24.45	113.13	252.30	387.54	3.3558	277.77
Yunnan	150.20	21.15	10.34	40.96	222.65	366.75	1084.91	1.6422	863.90
Tibet	4.12	0.59	0.45	5.88	11.04	304.95	621.52	135.3261	745.80
Shaanxi	148.59	5.40	7.17	34.68	195.84	483.60	507.35	6.4344	317.94
Gansu	72.91	18.01	6.68	33.44	131.03	281.25	252.30	26.4873	147.75
Qinghai	7.25	0.96	0.91	6.71	15.84	291.60	130.59	84.7287	199.48
Ningxia	31.17	1.18	2.11	12.04	46.50	420.00	29.69	4.7544	-12.05
Xinjiang	133.36	9.06	7.64	95.20	245.26	594.60	331.49	107.3394	193.56

4. Analysis on land use in carbon emissions associated with economic growth

4.1 The model and index selection

According to the environmental Kuznets hypothesis, there is a quadratic polynomial function between environmental quality and economic growth ("inverted U curve"), It referees to environmental pressures increase with the increase in per capita income, environmental stress declines as incomes increase when it is to a certain level[5].

The basic model is: $E_t = \partial + \beta_1 Y_t + \beta_2 Y_t^2$ (2)

Where, E_t for the country or region at time t the subject of environmental stress, commonly used indicators of environmental quality or pollutant emission intensity; Y_t is economic output at time t, it is usually expressed for GDP or per capita GDP. Inverted "U" shaped curve turning point (ie the quality of the environment to reach a turning point in the corresponding level of economic development), Formulas (3) can be solved from the first order derivative to formula (2):

$$Y_t = -\beta_1 / 2\beta_2 \qquad (3)$$

Y_t is Turning point for the environmental quality corresponding to the level of economic development. E_t in this article is expressed the carbon intensity of land use, Y_t is per capita agricultural output value.

We generally believed that the inverted "U" shaped curve of the basic functions are quadratic functional, three functional, the paper will test on the second and third function, we will select the best regression equation quadratic function if the situation is significant .

4.2 The carbon intensity of land and economic growth in the EKC authentication

The regression results shows(Table 4), F = 427.35, Sig .= 0.000, regression equation is overall significant, the independent variables significantly affects the dependent variable according to t statistics test results, at the same time it is through the DW test. Regression equation is:

$$E_t = 19.818 + 0.005Y_t - 2.6*10^{-7}Y_t^2 + u_t \qquad (4)$$

Table 4 the regression results between carbon intensity of agricultural land and agricultural output per capita

variable	Estimate	t test value	Sig.
∂	19.818	16.791	0.000
β_1	0.005	9.893	0.000
β_2	-2.6E-007	-6.060	0.001
Adjusted R Square		0.991	
F statistic		427.350（Sig.=0.000）	
DW test		2.205	
Curve shape		Inverted U- shape	
Inflection point （rgdp）		9615	

Note: The above test values are significant at the 0.01 level

From the regression equation, there is an inverted "U" shape between the carbon intensity of arable land and per capita agricultural output value, and the turning point in the critical value is 9615 yuan per capita agricultural output value, that is, when more than 9615 yuan per capita agricultural output value of the critical level, with per capita further increase in agricultural output value of cultivated land will reduce carbon intensity. However, for less than 9615 yuan per capita agricultural output value of the critical level of regions, there is an upward trend between agricultural production arable and land per capita carbon emission intensity, which increases as per capita agricultural output value of cultivated land will also increase the intensity of carbon emissions. According to this inflection point, the various regions of the actual 2008 level of per capita agricultural output compared to 9615 yuan threshold was found, Hainan (14,974 yuan), Liaoning (14,370 yuan), Inner Mongolia (13,090 yuan), Shanghai (13,022 yuan) , Jilin (12,623 yuan), Heilongjiang (12,446 yuan), Beijing (11,874 yuan), Shandong (11,375 yuan), Fujian (10,883 yuan), Jiangsu (10,234 yuan), Tianjin (10,013 yuan) per capita agricultural output value of 11 provinces and cities over inflection point, mainly in eastern provinces, developed cities and the Northeast region, with the further development of the agricultural economy, the land will reduce carbon intensity. Inflection point is lower than the other 20 provinces and cities, mainly in central and western provinces, the carbon intensity of land on the rise with economic growth. Overall, the national per capita level of 8041 yuan of agricultural output, indicating that in the next period of time, the process of China's economic growth will continue along with the increase in carbon intensity of arable land.

Carbon emissions caused by land on four aspects of emission intensity and per capita agricultural output value of further testing shows EKC, fertilizer, pesticide use and the carbon intensity of agricultural output per capita was a significant inverted U-curve relationship, their inflection point of view, even if the highest level of economic development in agriculture has yet to reach the inflection point of Hainan.

Agricultural mechanization, irrigation, the carbon intensity of energy use per capita agricultural output value with a linear relationship, does not have the inverted U-curve relationship between the intensity of their emissions within a very long time with the economic growth will significantly increase. It can be seen, in the short term, chemical fertilizers, pesticides, carbon emissions will be the agricultural land use in the main carbon source, and will be intensified. Medium to long term, as economic growth will be lower intensity, and agricultural mechanization, irrigation, such as the carbon intensity of energy use will increase. This conclusion is confirmed by reality gradually. With the development of modern agriculture, in the chemical fertilizer, pesticide use and gradually tightening the same time, agricultural mechanization in the national policy is being phased in under the Incentive, According to the data: collection of integrated mechanization level of crop farming in the year 2006-2009, on 4 consecutive years increased by 3 percentage points, showed a rapid development of agricultural mechanization trend. In addition, with the shortage of agricultural water resources and irrigation is not convenient, leading to demand for irrigation will also increase.

Table 5 the regression results between Carbon intensity of fertilizer use and agricultural output per capita

Variable	Estimate	t test value	Sig.
∂	10.228	12.228	0.000
β_1	0.004	11.065	0.000
β_2	-2.2E-007	-7.145	0.000
Adjusted R Square	0.991		
F statistic	455.234（Sig.=0.000）		
DW test	2.150		
Curve shape	Inverted U- shape		
Inflection point（rgdp）	18182		

Note: The above test values are significant at the 0.01 level

Table 6 the regression results between Carbon intensity of pesticide use and agricultural output per capita

Variable	Estimate	t test value	Sig.
∂	1.776	6.083	0.001
β_1	0.001	4.804	0.003
β_2	-2.6E-008	-2.470	0.045
Adjusted R Square	0.974		
F statistic	153.152（Sig.=0.000）		
DW test	1.786		
Curve shape	Inverted U- shape		
Inflection point（rgdp）	19231		

Note: The above test values were significant at the level of 0.01,0.05

5 Conclusion and Suggestions

5.1 The main conclusions

1. During 2000 to 2008 , average annual growth rate of carbon emissions on arable land was 2.47 percent, average annual growth of forest carbon sinks was 3.19 percent, grassland decreased rate of carbon sequestration but the trend is not obvious; higher carbon emissions farmland mainly concentrated in the central province areas and agriculture province, the higher the carbon intensity of cultivated land areas are mainly concentrated in eastern coastal provinces and major agricultural province; 9 provinces of agricultural land is the net carbon emissions, mainly in the agricultural province in urban areas and ecological vulnerability, the other 22 provinces and cities is a net carbon sink.

2. EKC Tests found that there is a significant inverted U-curve relationship between the carbon intensity of land use and per capita agricultural output value. There are 11 provinces and cities than 9615 yuan per capita agricultural output value of the inflection point, mainly in eastern provinces, developed cities and the Northeast region. The other 20 provinces and cities are lower than inflection point, mainly in central and western provinces. Further examination shows that, fertilizer, pesticide use and the carbon intensity of agricultural output per capita was a significant inverted U-curve relationship, but the inflection point of view, even the highest per capita agricultural output value has yet to reach the

inflection point of Hainan. Agricultural mechanization, irrigation, the carbon intensity of energy use per capita agricultural output value with a linear relationship, does not have the inverted U-curve relationship between the intensity of their emissions within a very long time with the economic growth will significantly increase.

5.2 promote the reduction of agricultural land use policy recommendations

1. Establish a low-carbon agricultural awareness and change the agricultural land use patterns. We should develop low-carbon agriculture, such as intensive agriculture, ecological agriculture, recycling of agriculture and so on.

2. Reduce the chemical fertilizer and pesticide usage, and strive to improve their efficiency. We should promote the use of conservation agriculture technologies, improve fertilizer use efficiency, and reduce fertilizer use， in order to reduce carbon emissions from agricultural land use.

3. Strengthen scientific and technological innovation; improve the use of low-carbon agricultural science and technology capacity to lead and technical support [6].

4. Strengthen the agricultural land resources, ecological protection, and continuously enhance the carbon sink capacity of agricultural land. Woodland, grassland, are the major carbon sink of agricultural land, so we should establish a special fund of agricultural land carbon sink, and constantly expand the scale of forest grassland, enhance the carbon sink capacity of agricultural land.

5. Promote the carbon market transactions of agricultural land use, initiative the enthusiasm of market players to increase carbon sinks to reduce emissions. Further improve the existing carbon exchange markets, build the formation of active market trading mechanism.

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References

[1] Huang Xianjin. Carbon emissions: land use regulation and control of new projects: the PRC Ministry of Land Resources Web site http://www.mlr.gov.cn/xwdt/jrxw/200912/t20091225_130977.htm（in Chinese）

[2] West TO, Marland G. A synthesis of carbon sequestration, carbone missions, and net carbon flux in agriculture: comparing tillage practices in the United States [J]. Agriculture Ecosystems and Environment, 2002,91.

[3] Fang Jinyun, Guo Zhaodi, Piao Shi Long. 1981 ~ 2000 terrestrial carbon sink estimates [J]. Science in China: D Series. 2007,37 (6) :804-812. （in Chinese）

[4] Zhi Jing, Gao Jiexi. Chinese food consumption of urban and rural residents in carbon emissions compared [J]. Progress in Geography, 2009(5):1-6（in Chinese）

[5] Grossman GM, Krueger A. Economic growth and environment [J]. Quarterly Journal of Economics, 1995,110:357-378.

[6] Lin Boqiang, Liu Xiying. China’ Carbon Dioxide Emissions under Urbanization Process:Influence Factors and Abatement Policies[J]. Economic Research Journal,2010(8):66-78（in Chinese）