

An Empirical Analysis of the Decoupling Relationship between Agricultural Carbon Emission and Economic Growth in Jilin Province

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Abstract: Agricultural carbon emission caused by agricultural economic growth has attracted wide attention in academic circles. Based on the input data of agricultural production materials from 1999 to 2014 in Jilin Province, this paper analyzes the decoupling relationship between agricultural carbon emission and economic growth in Jilin Province by using elastic decoupling method. Results show that the average annual growth rate of its total agricultural carbon emission was 4.28% from 1999 to 2014, with fertilizer being the main source and carbon emission from pesticide growing fastest. Meanwhile, weak decoupling is the main feature of agricultural carbon emissions and economic growth in terms of decoupling analysis.

1. Introduction

Global warming due to CO₂ emission has become one of the major environmental problems facing humanity, and climate change has important implications for global and our social and economic development. China is an agricultural country, and agriculture plays an important role in the development of national economy. With the development of agricultural modernization, the use of fertilizers, pesticides and agricultural machinery in agricultural production has increased year by year. Agriculture has become the second largest source of greenhouse gases ^[1]. Initial National Communications on Climate Change issued in 2000 states that agricultural greenhouse gas emission accounts for about 17% of China's total carbon emissions ^[2]. Jilin Province lies in the middle of northeast China. It is of temperate continental monsoon climate, with rainfall and sunshine in the same period. It is rich in arable land, and the soil contains much organic matter good for crops. It is the main grain production and export area. Grain production increased from less than 5×10^6 t in the early days of new China to 3.647×10^7 t in 2015. The rapid increase in grain production has been accompanied by significant agricultural consumption. The amount of agricultural plastic film used in Jilin Province was 8.43×10^4 t in 2014; pesticide usage is 5.05×10^4 t; the amount of pesticide used is 5.05×10^4 t; the purity application of fertilizer is 2.267×10^6 t; the total power of agricultural machinery is 2.9191×10^7 kw. The consumption of these agricultural substances directly or indirectly increases greenhouse gas emissions. Therefore, studying the relationship between agricultural carbon emissions and agricultural output value and exploring the main factors that affect agricultural carbon emissions is of great significance for changing agricultural production mode and developing low-carbon agriculture.

2. Research methodology and data sources

2.1 Accounting of agricultural carbon emission

At present, the measurement method, material balance algorithm and carbon emission coefficient



method are mainly used in the international environmental statistics work on carbon emission accounting^[3]. Among them, the material balance algorithm is mainly used to account for the carbon emissions generated by the consumption of fossil fuels such as coal, oil, and natural gas. Agricultural carbon emissions mainly refer to the carbon emissions generated by the input of production materials such as fertilizers, pesticides, and agricultural plastic films in the agricultural production process. Taking into account the specific situation of Jilin Province and the availability of data and information, the accounting of agricultural carbon emissions in this paper is based on the previous carbon emission calculation methods. The paper accounts for the agricultural carbon emissions from 1999 to 2014 in Jilin Province from the six aspects such as fertilizers, agricultural plastic films, pesticides, agricultural irrigation, tillage (the actual planting area of crops) and agricultural diesel. Its computational model is as follows:

$$E = \sum e_i = \sum T_i \times \delta_i \quad (1)$$

In the formula: E —total agricultural carbon emission; e_i —agricultural carbon emission from source No. i ;

T_i —consumption of agricultural carbon emission source No. i ; δ_i —agricultural carbon emission index from source No. i ;

According to the previous research results^[4-6, 10], the agricultural carbon emission factors constructed is shown in Table 1.

Tab. 1 Agricultural carbon emission coefficient and its sources

source of carbon emission	emission index
fertilizer	0.895 6 kg·kg ⁻¹
agricultural plastic film	5.18 kg·kg ⁻¹
pesticide	4.934 1 kg·kg ⁻¹
agricultural irrigation	266.48kg·hm ⁻²
surface tillage	312.6kg·km ⁻²
agricultural diesel oil	0.592 7 kg·kg ⁻¹

Carbon intensity refers to carbon emission of per unit sown area. Its calculation formula is as follows:

$$A = \frac{E}{B} = \frac{\sum e_i}{B} = \frac{\sum T_i \times \delta_i}{B} \quad (2)$$

In the formula: A —intensity of agricultural carbon emission; B —area of cultivated land

2.2 Decoupling theory and the establishment of decoupling model

The decoupling theory originated in the field of physics. The Organization for Economic Cooperation and Development introduced it into the field of environmental economics. It is mainly used to analyze the relationship between economic growth and resource and environmental pressure^[7]. The theory holds that during a period of time, when economic growth exceeds the resource and environmental problems caused by economic activities, there is a certain decoupling relationship between the two. At present, there are two main types of decoupling analysis models. One is the OCED decoupling index analysis model proposed by the Organization for Economic Cooperation and Development; the other is the Decoupling Elastic Analysis Model Proposed by Tapio for the Decoupling of European Traffic and GDP^[8]. This paper constructs a decoupling model of agricultural carbon emissions and economic growth based on the Tapio decoupling model:

$$C = \frac{\Delta E/E}{\Delta GDP/GDP} \quad (3)$$

ΔE —change rate of agricultural carbon emission; ΔGDP —change rate of plantation value; GDP —plantation value

According to the size of the decoupling elastic value C , the decoupling relationship between carbon emissions and economic growth can be divided into eight types as shown in Table 2.

Tab. 2 Division and meaning of decoupling elasticity types ^[8-9]

decoupling	state	decoupling index C	ΔGDP 、 ΔE change rate	meaning of decoupling
negative decoupling	strong negative decoupling	$C < 0$	$\Delta G/G < 0, \Delta E/E > 0$	an economic recession, a decline in GDP, a rise in carbon emissions
	weak negative decoupling	$0.8 > C \geq 0$	$\Delta G/G < 0, \Delta E/E < 0$	a decline in both GDP and carbon emission, but the rate of former is bigger than that of the latter
	dilated negative decoupling	$C > 1.2$	$\Delta G/G > 0, \Delta E/E > 0$	a rise in both GDP and carbon emission, but the rate of latter is bigger than that of the former
decoupling	strong decoupling	$C < 0$	$\Delta G/G > 0, \Delta E/E < 0$	an economic growth, a rise in GDP, a decline in carbon emission
	weak decoupling	$0.8 > C \geq 0$	$\Delta G/G > 0, \Delta E/E > 0$	a rise in both GDP and carbon emission, but the rate of former is bigger than that of the latter
	recession decoupling	$C > 1.2$	$\Delta G/G < 0, \Delta E/E < 0$	a decline in both GDP and carbon emission, but the rate of latter is bigger than that of the former
link	expansion link	$1.2 \geq C \geq 0.8$	$\Delta G/G < 0, \Delta E/E > 0$	Economic growth and carbon emission are still in non-decoupling state
	recession link	$1.2 \geq C \geq 0.8$	$\Delta G/G < 0, \Delta E/E < 0$	Mainly to prevent over-interpretation of minor changes ^[10]

2.3 Data sources

The basic data indicators on which this study is based include planting GDP, fertilizer (folding purity), agricultural film, pesticides, agricultural diesel, agricultural irrigation, and planting area of crops. These data are collected and collated in the Jilin Provincial Statistical Yearbook and the Jilin Provincial Statistical Bulletin (published) and the Yearbook of Rural Statistics of China. The sample ranges from 1999 to 2014 and has a total length of 16 years.

3. Results and analysis

According to Formula 1 and Formula 2, the total amount of agricultural carbon emissions and agricultural carbon emission intensity in Jilin Province from 1999 to 2014 were calculated. The results are shown in Table 3 and Figure 1.

3.1 Time series analysis of carbon emissions and intensity in agriculture

Judging from the total agricultural carbon emissions from 1999 to 2014 in Jilin Province (Figure 1), the overall growth trend was showed. The agricultural carbon emission increased from 1.89916×10^6 t in 1999 to 3.55507×10^6 t in 2014. The average annual growth rate was 4.28 %, and an accelerated growth trend was shown after 2006. According to the growth of total agricultural carbon emissions in Jilin province, the process of change can be divided into two stages. The first phase (1999-2005) was a period of fluctuating growth, whose overall performance is the change process of “falling-growing-falling”. The second stage (2006-2014) was a period of rapid growth. The total carbon emissions increased from 2.52788×10^6 t in 2006 to 3.55507×10^6 t in 2014, with an average annual growth rate of 4.61 %. The carbon emissions from various agricultural sources also increased to varying degrees (Figure 2), with the fastest growth rate of 7.20 % for pesticides, followed by an average annual growth rate of 6.22% for diesel, 4.56% for fertilizers and 3.66% for agricultural plastic films.

Carbon emissions from tillage and irrigation grew slowly, with rates of 2.18% and 1.55% respectively.

According to the structure of agricultural carbon emissions in Jilin province (Figure 2), fertilizer emissions are significantly higher than other carbon sources among the six major sources. On the average of 16 years, fertilizer application accounted for the largest carbon emissions, accounting for 53.22% of the total carbon emissions, followed by irrigation, agricultural film and agricultural diesel, accounting for 16.03%, 13.21% and 10.52% respectively, and pesticides and tillage have the least carbon emissions with proportion of 6.45% and 0.57%. Among the six carbon sources, except for the partial fall of the curve of fertilizer and agricultural film, the other four curves have been steadily rising.

Judging from the agricultural carbon emission intensity in Jilin Province (Figure 3), there is a fluctuating growth trend. It increased from 466.786 kg/hm^2 in 1999 to 633.104 kg/hm^2 in 2014 with an average annual growth rate of 2.05 %.

As can be seen from the above, with the development of the agricultural economy and the improvement of the level of agricultural modernization, the use of agricultural production materials

such as fertilizers, pesticides, and agricultural plastic films has increased, so that the amount of carbon emissions in agriculture has also shown an increasing trend. Accompanied by the vigorous promotion of the project of increasing grain production by 10 billion kilograms in Jilin Province, the protection and collation of arable land resources, agricultural mechanization and modernization, will be improved [11], and the use of chemical fertilizers, pesticides and other substances will further increase. As a result, agricultural carbon emissions will continue to increase in the future, and ecological and environmental pressures will increase. Therefore, realizing the decoupling of agricultural economic growth and carbon emissions will be the key to Jilin's agricultural development in the future.

Tab. 3 Agricultural Carbon Emissions from 1999 to 2014 in Jilin Province

Year	Fertilizer /(10 ⁴ t)	Agricultural plastic film /(10 ⁴ t)	Pesticide /(10 ⁴ t)	Agricultural diesel /(10 ⁴ t)	Irrigation /(10 ⁴ t)	tillage /(10 ⁴ t)	Total emission /(10 ⁴ t)	Sequential speed /%	Emission intensity /(kg·hm ⁻²)	Annual growth rate /%
1999	104.068 7	25.485 6	8.782 7	15.647 3	34.461 2	1.270 5	189.716 0	-	466.786 4	-
2000	100.396 8	25.848 2	9.720 2	16.654 9	35.042 1	1.270 9	188.933 1	-0.41	464.711 5	-0.44
2001	102.188 0	37.347 8	11.891 2	20.033 3	36.854 2	1.264 7	209.579 2	10.93	518.029 5	11.47
2002	104.785 2	33.566 4	11.743 2	19.203 5	39.945 4	1.465 4	210.709 1	0.54	449.493 6	-13.23
2003	109.531 9	30.510 2	11.644 5	20.685 2	41.197 8	1.474 6	215.044 2	2.06	455.882 2	1.42
2004	142.490 0	31.080 0	12.680 6	23.945 1	42.503 6	1.533 0	254.232 3	18.22	518.418 2	13.72
2005	123.682 4	30.924 6	14.259 5	24.004 4	43.001 9	1.548 3	237.421 1	-6.61	479.338 4	-7.54
2006	131.384 5	33.255 6	17.022 6	25.960 3	43.606 8	1.558 2	252.788 0	6.47	507.138	5.80
2007	138.280 6	33.307 4	18.601 6	25.931 4	43.718 7	1.575 6	261.415 3	3.41	518.650 3	2.27
2008	146.699 3	35.586 6	19.983 1	31.590 9	44.739 3	1.562 4	280.161 6	7.17	560.525	8.07
2009	156.013 5	36.519 0	20.920 6	34.198 8	44.867 2	1.587 3	294.106 4	4.98	579.223 3	3.34
2010	163.715 7	37.296 0	21.117 9	36.154 7	46.015 8	1.632 2	305.932 3	4.02	585.920 1	1.16
2011	174.821 1	42.786 8	22.499 5	37.873 5	48.811 1	1.632 5	328.424 5	7.35	628.888 6	7.33
2012	185.120 5	43.992 7	25.281 8	39.592 4	49.349 4	1.661 5	344.998 3	5.05	649.090 9	3.21
2013	194.166 0	44.959 8	25.169 3	40.718 5	49.397 4	1.692 1	356.103 1	3.22	657.854 3	1.35
2014	203.032 5	43.686 0	24.925 6	38.703 3	43.404 3	1.755 3	355.507 0	-0.17	633.104 2	-3.76
Average growth rate /%	4.56	3.66	7.20	6.22	1.55	2.18	4.28	-	2.05	-

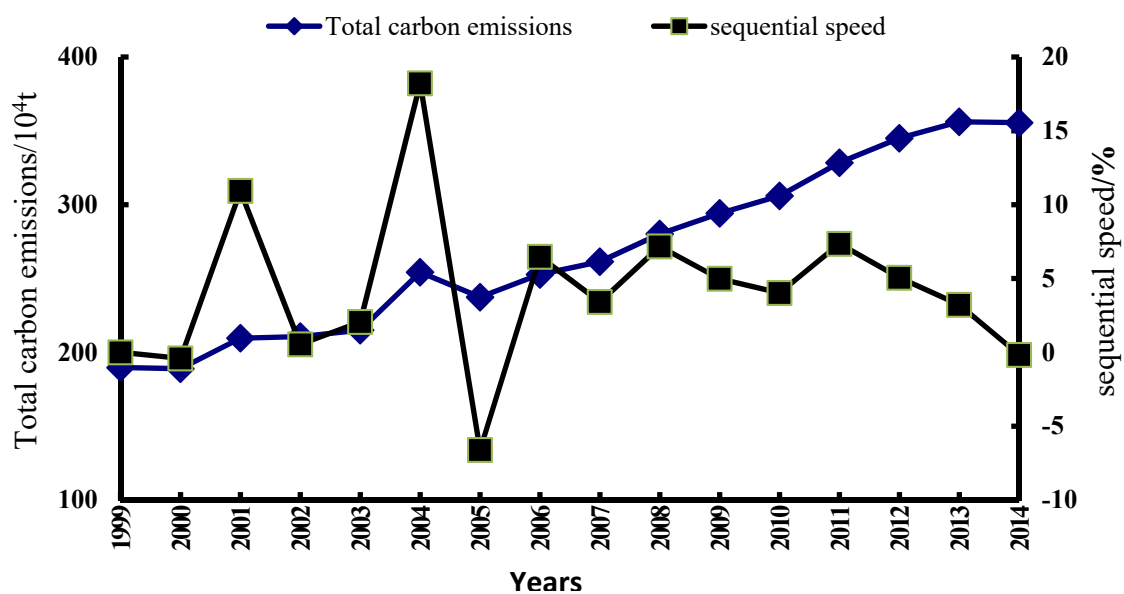


Fig. 1 Total agricultural carbon emissions and average annual growth rate from 1999 to 2014 in Jilin Province

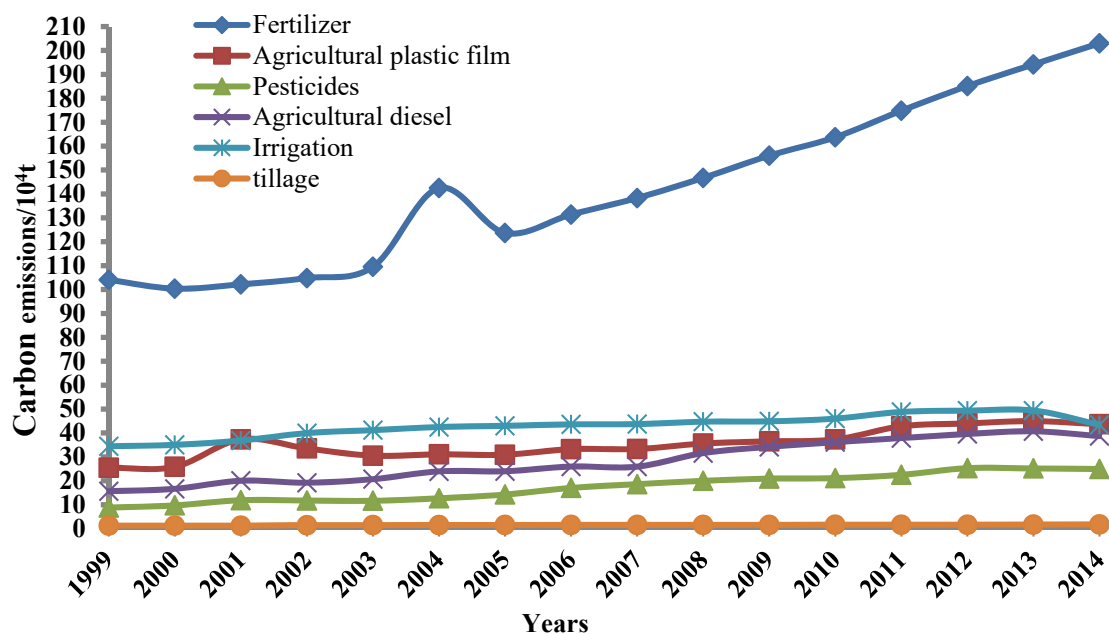


Fig. 2 Structure and its change of agricultural carbon emission source from 1999 to 2014 in Jilin Province

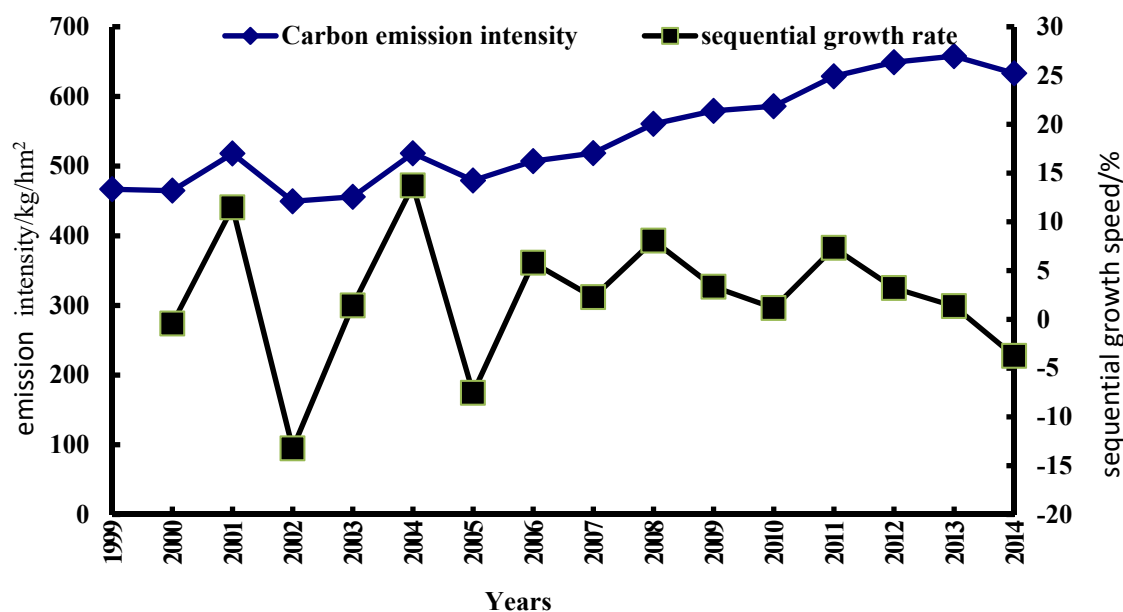


Fig. 3 Intensity of agricultural carbon emissions and average annual growth rate from 1999 to 2014 in Jilin Province

3.2 Decoupling analysis of agricultural carbon emissions and economic growth

According to Formula 3, the elastic index of the decoupling of agricultural carbon emissions from economic growth in different periods in Jilin Province is measured. The results are shown in Table 4.

Tab. 4 Decoupling evaluation of agriculture carbon emissions and economic growth in Jilin Province

Year	$\Delta E/E$	$\Delta G/G$	Decoupling Index C	Decoupling State
2000	-0.004 1	-0.175 4	0.023 5	weak negative decoupling
2001	0.109 3	0.265 8	0.411 1	weak decoupling
2002	0.005 4	0.011 9	0.453 4	weak decoupling
2003	0.020 6	0.068 5	0.300 1	weak decoupling
2004	0.182 2	0.109 3	1.668 0	dilated negative decoupling
2005	-0.066 1	0.065 6	-1.007 9	strong decoupling
2006	0.064 7	0.152 3	0.425 1	weak decoupling
2007	0.034 1	0.093 8	0.363 8	weak decoupling
2008	0.071 7	0.147 3	0.486 9	weak decoupling
2009	0.049 8	0.037 7	1.320 0	dilated negative decoupling
2010	0.040 2	0.115 1	0.349 3	weak decoupling
2011	0.073 5	0.177 1	0.415 2	weak decoupling
2012	0.050 5	0.143 2	0.352 4	weak decoupling
2013	0.032 2	0.081 5	0.394 8	weak decoupling
2014	-0.001 7	0.064 1	-0.026 1	weak decoupling

As can be seen from Table 4, except for the weak negative decoupling and expansion negative decoupling in 2000, 2004 and 2009, which were not ideal, the agricultural carbon emissions in Jilin Province were weakly decoupled and strongly decoupled from agricultural output growth in most of the years from 1999 to 2014. It shows that the agricultural carbon emissions in Jilin province are less driven by the growth of agricultural output, and their growth rate is lower than the growth rate of agricultural output. On the other hand, it also shows that the output value of planting industry in Jilin Province has gradually improved from relying on inputs of fertilizers, pesticides, and other production materials, and the high-consumption extensive agricultural development mode, and the contradiction between agricultural development and resources and environment is gradually eased.

The growth rate of carbon emissions reflects the changes in the government's energy conservation and emission reduction policies, and GDP growth rate reflects macroeconomic changes^[12]. According to the changes in the growth rate of agricultural carbon emissions and the growth rate of crop production in Jilin Province, it can be divided into three stages.

1) From 2000 to 2004 (the first phase), the average growth rate of agricultural carbon emissions in Jilin Province was 6.26 %. In the same period, the average growth rate of the planting industry's GDP was 5.60 %, and the growth rate of agricultural carbon emissions was faster than the growth rate of the planting industry's GDP. In 2000, the output value of the planting industry and carbon emissions in Jilin Province decreased, but the decline rate of the output value of the planting industry was greater than that of carbon emissions, and agricultural carbon emissions and the output value growth of the planting industry was in a state of weak and negative decoupling. The main reason for this is that during the Ninth Five-Year Plan period, China was affected by the reform of state-owned enterprises and the Asian financial crisis, and the support for agricultural production was not strong. The overall development of the agricultural economy in Jilin Province was relatively poor. During this period, the total agricultural output value and material expenses of Jilin Province experienced negative growth^[13]. Secondly, in 2000, Jilin Province encountered the most severe drought in history, with a total area of $3.662 \times 10^6 \text{ hm}^2$ ^[14], directly leading to the reduction of agricultural output value. In 2004, the output value of the planting industry and carbon emissions in Jilin Province increased, but the growth rate of carbon emissions was greater than that of the planting value, and the agricultural carbon emissions and the growth of the planting value were in a state of expansion and negative decoupling. The reason for this is that in 2004, the Central Committee issued the "No. 1 Document" to implement the policy of reducing and subsidizing agriculture. At the same time, Jilin Province also implemented the national policy with corresponding measures, which aroused the enthusiasm of farmers' production, and increased the input of fertilizers, pesticides, agricultural film and other production materials. During

this period, the growth rates of agricultural output and material costs in Jilin Province were 7% and 12.21% respectively, which was a significant improvement over the negative growth rate in 2000^[14].

2) From 2005 to 2009 (the second phase), the average growth rate of agricultural carbon emissions in Jilin Province was 3.08 %, and the average growth rate of the planting industry's GDP during the same period was 9.93 %, showing that the growth rate of agricultural carbon emissions is changing from higher than to lower than that of the output value of the planting industry. Therefore, the elastic characteristics of decoupling take the weak decoupling as the main form. In 2009, the growth rate of the planting industry's GDP was smaller than that of agricultural carbon emissions, and the agricultural carbon emission was in a state of negative decoupling from the growth of the output value of the planting industry. The reason for this is that the climate in Jilin Province is an obvious continental monsoon climate. The distribution of precipitation seasons is uneven. There is more precipitation in summer and autumn and less precipitation in winter and spring. It is very easy to generate spring drought. In addition, the agricultural infrastructure is not perfect and the utilization rate of water resources is low, resulting in weak ability to resist natural disasters in agricultural production. In 2009, the area affected by agricultural disasters in Jilin Province reached $2.671 \times 10^6 \text{ hm}^2$, which was much higher than the $5.797 \times 10^5 \text{ hm}^2$ in 2008^[15]. As a result, the growth rate of crop production value is much lower than that in 2008, which increases the decoupling elasticity value.

3) From 2010 to 2014 (the third stage), the average growth rate of agricultural carbon emissions in Jilin Province was 3.89%, and the average growth rate of the planting industry's GDP during the same period was 11.62%. During this period, the growth rate of agricultural carbon emissions and crop production value has slowed, and the growth rate of carbon emissions in five years has been lower than that of crop production value. Therefore, the characteristics of decoupling elasticity mainly take weak decoupling and strong decoupling as the main forms. The reason is that although the rapid development of agriculture has led to an increase in agricultural material consumption, the progress of agricultural science and technology and the promotion of circular agriculture and ecological agriculture modes in Jilin Province has improved the utilization rate of agricultural production materials, thus slowing down gradually the speed of agricultural carbon emissions.

4. Conclusion and suggestion

Based on the perspective of agricultural material input, the carbon emissions of Jilin Province from 1999 to 2014 were accounted for according to the method of carbon conversion coefficient made by the predecessors. The time series analysis shows that the input of agricultural materials is the main reason for increasing agricultural carbon emissions. In terms of time, the annual average growth rate of total agricultural carbon emissions in Jilin Province from 1999 to 2014 was 4.28 %. The carbon emissions of various types of agricultural carbon sources also showed great differences. Among them, fertilizer application is the main source of carbon emissions in agriculture, accounting for more than 1/2 of the total agricultural carbon emissions. From the calculation results of decoupling elasticity value, the weak decoupling between agricultural carbon emissions and economic growth is the main type. It shows that the current agricultural production process in Jilin province has gradually emerged from the predicament of high pollution and low output, which has played a positive role in energy conservation and emission reduction in agriculture, and the conflict between agricultural economy and the environment has gradually decreased.

With the economic and social development, the carbon emissions caused by agricultural production will gradually decrease. However, in order to achieve the desired strong decoupling of agricultural carbon emissions from economic growth in Jilin province, the government and farmers should also pay great attention to the carbon emissions caused by inputs of agricultural materials such as fertilizers, pesticides and agricultural film in the future agricultural development. In the process of agricultural production, while strengthening scientific and technological innovation, we will strengthen agricultural infrastructure construction, increase the utilization rate of agricultural resources, and pursue a low-carbon agricultural development path with characteristics of resource conservation, environmental friendliness and ecological civilization, so as to make our due contribution to China's

energy conservation and emission reduction goal of 2020.

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