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Spatial and Temporal Disparities in Agricultural Carbon Emissions in Xinjiang and Decomposition of Impact Factors

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This paper describes the measurement method for agricultural carbon emissions in the Xinjiang Uygur Autonomous Region over the past 16 years. Here is analysis on spatial and temporal disparities in the carbon emissions with diverse characteristics. LMDI model decomposes some key factors that affect agricultural carbon emissions. The results reveal that the gross carbon emissions from agriculture in Xinjiang show an upward trend during the past 16 years, while the carbon intensity gets moderate; the carbon emissions in various prefectures present different intensities and patterns. Agricultural economy development level and the size of agricultural labor force have a positive impact on carbon emissions, whereas agricultural production efficiency and industrial structure go the other way around.

1. Introduction

A boom in greenhouse gases such as carbon dioxide caused by human activities is no doubt the main driver of global climate warming (Yadav et al., 2017). Agriculture is the second largest source of greenhouse gas emissions, next to industries (Sununta et al., 2018). China's agricultural carbon emission as a percentage of the national total is 15 %-20 % now (Xu et al., 2016). In order to fulfill China's commitment for emission reduction made to the international community, not only should people conserve energy and reduce consumption in the industrial circle, but also the agricultural system must be fully developed into one with more advantages such as emission reduction and carbon sinks (Tian et al., 2016). Therefore, it is mandatory for human to grasp the law of carbon emissions from agricultural systems and identify the driving factors that affect agricultural carbon emissions, which can support to develop reasonable policies (Biagini et al., 2014) in favor of wrapping up the carbon emission reduction.

Currently, the carbon emissions from agriculture are discussed from several dimensions, i.e. the estimation of carbon emissions(Han et al., 2013), the relationship between carbon emissions and economic growth in agriculture (Gao et al., 2017), the issues about fairness and efficiency of carbon emissions(Conant, 2011), ecological compensation mechanism with agricultural carbon sinks(Ghosh et al., 2012), the estimation on agricultural carbon emission reduction potential, and carbon emissions and sinks occurred by land use change (Zhang et al., 2017), etc. Most studies focus on the calculation and comparison against agricultural carbon emissions countrywide, but rare involve what it is in the arid areas of west China where there are fewer people and more lands planted in the ecologically fragile environments. Xinjiang is an important production base for grain, cotton, fruits and livestock in China. With the huge inputs of chemicals such as fertilizers, pesticides, agricultural films, and agricultural diesel, as well as the continuous proliferation of animal husbandry, the carbon dioxide directly or indirectly generated from agricultural systems racks up, speeding up climate warming and seriously worsening agricultural ecology and people's lives. Based on the estimations of total carbon emissions from agriculture and its intensity in Xinjiang in the past 16 years, the LMDI model is applied to decompose factors affecting agricultural carbon emissions in the hope of providing a theoretical basis for improving agricultural carbon emission reduction potential aiming at arid areas of west China.

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2. Study method and data sources

2.1 Estimation of agricultural carbon emissions

The carbon emissions from agricultural production attribute to inputs of agricultural materials, the consumption of agricultural energy resources, the ploughing of agricultural lands, rice cultivation, straw combustion, livestock breeding and management of their excrement. Given that the rice planting area in Xinjiang is small and the straw is basically returned to the field, this paper only focuses on the carbon emissions caused by agricultural film, pesticides, chemical fertilizers, agricultural diesel, plowing and livestock breeding. The total carbon emissions are calculated by the formula as follows:

$$C = \sum C_i = \sum A_i B_i \tag{1}$$

Where, C is the total carbon emissions; C_i is the carbon emissions from various types of carbon sources; A_i, B_i are the number of various types of carbon sources and carbon emission coefficients, respectively. The sources and coefficients of relevant carbon emission are shown in Table 1. The carbon emission factors of agricultural film, pesticides, fertilizer, diesel, and ploughing were 5.18 kg/kg, 4.9341 kg/kg, 0.8956 kg/kg, 0.5927 kg/kg, and 312.6 kg/hm^2, respectively. The greenhouse gases caused by livestock breeding are mainly CH_4 and N_2O. The greenhouse gases generated by livestock breeding are mainly CH_4 and N_2O discharged during enteric fermentation of livestock and management of livestock manure. For easy calculation, the greenhouse gases such as CO_2, CH_4, N_2O are generally converted into standard carbon equivalents. After conversion, the carbon emission factors of cattle, horses, donkeys, pigs, goats, and sheep respectively are 519.23 kg/year/one, 246.88 kg/year/one, 187.29 kg/year/one, 77.17 kg/year/one, 62.07 kg /year/one and 61.93 kg/year/one.

2.2 LMDI factor decomposition

The LMDI decomposition has unique advantages such as path independence, zero residual error, and enhanced model persuasion. It is widely used in factor decomposition field. The formula for decomposing the factors that affect agricultural carbon emissions in Xinjiang was built as follows:

$$C = PF \times SF \times EF \times L = \frac{C}{ZX} \times \frac{ZX}{AGDP} \times \frac{AGDP}{L} \times L \tag{2}$$

Where, C is the total amount of agricultural carbon emissions; ZX is the sum of the output values of crop production and animal husbandry; AGDP is the total output value of agriculture, forestry, animal husbandry and fishery; L is the total agricultural labor force; PF, SF and EF represent agricultural production efficiency, industrial structure and economic development level, respectively. The change in carbon emissions (C_t) during period t relative to base emissions (C_0) can be expressed as:

$$\Delta C = C_t - C_0 = \Delta CPF + \Delta CSF + \Delta CEF + \Delta CL \tag{3}$$

Where, ΔCPF, ΔCSF, ΔCEF and ΔCL represent the contribution values of each factor to the total carbon emissions, and are expressed by the formulae:

$$\begin{aligned} \Delta CPF &= \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln \frac{PF_t}{PF_0}; \Delta CSF = \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln \frac{SF_t}{SF_0} \\ \Delta CEF &= \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln \frac{EF_t}{EF_0}; \Delta CL = \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln \frac{L_t}{L_0} \end{aligned} \tag{4}$$

2.3 Data sources

All figures are sourced from the Statistical Yearbook of Xinjiang, 2002-2017, and the Statistical Yearbooks of various counties. Among them, the chemical fertilizer used for agriculture is a pure dosage as converted; the ploughing area is based on the actual area sown in each province in current year; and the size of agricultural labor force is based on the number of employees in the primary industry, and for cattle, horses, donkeys, pigs, goats, and sheep, the number of the livestock at the end of each year shall prevail. In order to eliminate the impact of price fluctuations, the year of 2000 is taken as the base year to convert the output values of the crop production and the animal husbandry, and the total output value of agriculture, forestry, animal husbandry and fishery into the actual values.

3. Analysis of study results

3.1 Analysis on spatial and temporal disparities of agricultural carbon emissions in Xinjiang

(1) Timing sequence change characteristics

Agricultural carbon emissions: As shown in Table 1, the total carbon emissions from agriculture in Xinjiang show an upward trend, that is, from 7,004,400 tons in 2001 to 9,824,600 tons in 2016, with an annual average growth rate of 2.28%, and present the three-stage feature of first rise - decline - rise again. The average annual growth rates of carbon emissions caused by agricultural film, pesticides, fertilizers, agricultural diesel, ploughing, and livestock breeding reached 6.45 %, 4.62 %, 8.06 %, 4.41 %, 4.25 %, and 0.02 %, respectively. The accumulated carbon emissions from livestock breeding hit upon the maximum of 87.395 million tons, 66.60 % of the total; and also showed the “rise-decline-rise” three-stage change characteristic, that is, increased from 5.37 million tons in 2001 to 6.4723 million tons in 2005, and from 2006, gradually declined till to 4.3711 million tons in 2011; from 2012, it slowly climbed up and reached 5.378,8 tons in 2016. Followed by the carbon emissions caused by fertilizer input, it was 22.5613 tons, 17.2 % of the total. The carbon emissions from agricultural film inputs ranks third. Relatively small amounts of the carbon emissions were sourced from agricultural diesel, pesticides and plowing, 4.41 %, 1.1 % and 0.18 %, respectively.

Agricultural carbon emission intensity: it is expressed by the carbon footprint born by crops per unit sown area. As shown in Figure 1, the carbon intensity of agriculture in Xinjiang as a whole shows a downward trend, specifically a three-stage feature of “rise - decline - nudge-up”, that is, the carbon emission intensity first increased from 2081.83 kg/hm^2 in 2001 to the top of 2276.17 kg/hm^2 in 2005, then slowly decreased from 2059.60 kg/hm^2 in 2006 to 1515.78 kg/hm^2 in 2011, from then on, it slowly heaved again to 1601.33 kg/hm^2 in 2016. Although the total carbon emissions from agriculture were on the rise, the carbon intensity has declined due to the continuous growth in the sown area of crops within the past 16 years.

Table 1: Agricultural carbon footprint in Xinjiang in 2001-2016 *Unit: 10^{4}t*

Year	Agricultural films	Pesticides	Fertilizer	Diesel	Plough	Livestock breeding	Total
2001	54.24	6.22	74.60	27.32	1.06	537.00	700.44
2002	50.16	5.68	75.50	23.70	1.09	563.27	719.40
2003	51.48	5.98	81.27	26.31	1.08	600.48	766.60
2004	54.72	6.07	88.82	27.08	1.12	626.82	804.63
2005	60.05	7.19	96.52	28.74	1.17	647.23	840.90
2006	66.63	7.68	107.16	29.33	1.31	646.77	858.88
2007	73.21	8.18	117.79	29.93	1.37	615.82	846.30
2008	87.56	9.06	133.35	33.96	1.42	450.57	715.92
2009	81.99	8.95	138.80	35.32	1.47	515.24	781.77
2010	88.43	8.98	150.07	36.92	1.49	445.92	731.81
2011	94.78	9.54	164.50	40.06	1.56	437.11	747.55
2012	97.26	9.79	172.58	42.73	1.61	504.08	828.05
2013	107.05	10.50	182.00	45.87	1.63	516.74	863.79
2014	136.19	15.02	212.24	47.47	1.87	540.13	952.92
2015	139.29	12.75	222.19	51.14	1.92	553.54	980.83
2016	138.55	12.25	238.74	52.16	1.98	538.78	988.46
Total	1381.59	143.84	2256.13	578.04	23.15	8739.5	13122.25
Average growth	6.45%	4.62%	8.06%	4.41%	4.25%	0.02%	2.28%

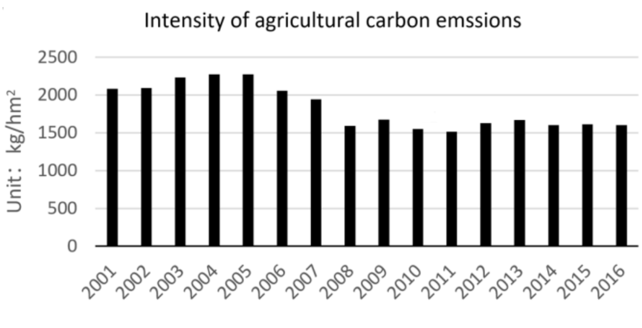

Figure 1: Agricultural carbon intensity in Xinjiang in 2001-2016

(2) Spatial difference characteristics

The agricultural carbon emissions and its intensities in 14 prefectures of Xinjiang were calculated in Table 2.

Differentiation in carbon intensity: the carbon emission intensity is not susceptible to agricultural production scale and resource endowments. It can objectively reflect the carbon emission level of an area and is conducive to horizontally regional comparison. The results from measurement and calculation show that agricultural carbon emission intensity in Xinjiang shows the characteristics of being high in the north, low in the south, and centered in the east, and peaks in Urumchi (5894.67 kg/hm^2). Although the total carbon emissions in the area are not the maximum, relatively small area sown for crops pulls up the carbon emission intensity. There is a root cause, that is, the productivity of agricultural lands per unit in this area more depends on the high input of production materials such as fertilizers. The carbon emission intensity in Aksu reaches the minimum of 1587.01 kg/hm^2. It can also be divided into three levels: ①Areas where it is greater than 4000 kg/hm^2 include Urumqi and Bozhou. ②Areas where it ranges from 2000-4000 kg/hm^2 include Yili, Kezhou, Altay, Hotan, Turpan and Kumul. ③Areas where it is less than 2000 kg/hm^2 include Karamay, Bazhou, Changji, Tacheng, Aksu, and Kashgar. Differentiation in structure of carbon emissions: as a percentage of each carbon source, it is divided into three types: ①Leading areas for planting industry: Urumqi, Bozhou, Bazhou and Aksu. ②Leading areas for livestock breeding: Kezhou, Altay, Yili, Hotan and Humul. ③Composite areas, i.e. those where the proportions of carbon emissions from crops and animal husbandry are equivalent, include Changji, Turpan, Karamay, Tacheng, and Kashgar.

Table 2: Agricultural carbon emissions and carbon intensity in different prefectures of Xinjiang in 2016

Prefecture	Planting industry Emissions(10^4t)	Planting industry Ratio (%)	Livestock Emissions(10^4t)	Livestock Ratio (%)	Total emissions (10^4t)	Carbon intensity (kg/hm^2)
Urumchi	16.97	64.80	9.22	35.20	26.19	5894.67
Karamay	1.66	53.72	1.43	46.28	3.09	1924.03
Changji	47.41	48.45	50.44	51.55	97.85	1787.67
Bortala Mongol	65.55	86.18	10.51	13.82	76.06	4130.10
Yili Kazakh	44.86	28.35	113.38	71.65	158.24	3131.05
Tacheng	49.24	49.64	49.96	50.36	99.2	1598.09
Altay	15.05	24.60	46.14	75.40	61.19	2645.83
Turpan	7.49	52.41	6.8	47.59	14.29	2330.40
Kumul	6.69	39.92	10.07	60.08	16.76	2256.33
Bayingolin Mongol	51.55	63.63	29.47	36.37	81.02	1939.90
Aksu	85.49	63.81	48.49	36.19	133.98	1587.01
Kizilsu Kirghiz	5.3	23.45	17.3	76.55	22.6	3078.60
Kashi	93.63	49.85	94.21	50.15	187.84	1594.62
Hotan	20.19	35.24	37.11	64.76	57.3	2150.98

3.2 Decomposition of factors affecting agricultural carbon emissions

Based on the agricultural carbon emissions measured in the previous section, the LMDI model is applied to decompose the factors that affect agricultural carbon emissions in Xinjiang. As shown in Table 3, in 2002 - 2016, the elevation of agricultural production efficiency has effectively suppressed the carbon emissions and contributed to a cumulative 43.6093 million tons of carbon reduction, so that it acts as a key factor to accelerate carbon emission reduction. It means that the agricultural production efficiency as a key factor will lead to an annual decrease of 2.9073 million tons agricultural carbon emissions on the premise that other factors remain unchanged.

As compared with agricultural production efficiency, the agricultural industry structure adjustment contributes less to agricultural carbon emission reduction and there are greatly different contributions over the years. However, it has helped reduce cumulative 736,400 tons carbon emissions, i.e. an average annual 49,100 tons, which shows that in the case of other constant factors, the agricultural industry structure adjustment promotes carbon emission reduction. In the past 15 years, Xinjiang's agricultural structure adjustment had directed to descending the proportion of animal husbandry, increasing the proportion of planting crops, and greatly expanding the area for planting fruits and vegetables. Although the carbon emissions from animal husbandry have reduced a little, pesticides and fertilizers used in the planting industry in large doses constantly lead to flooding in carbon emissions. In this regard, the agricultural industry structure adjustment contributes less to agricultural carbon reduction.

It is positive for the contribution of the agricultural economy development level to the total carbon emissions from agriculture, which shows that the buildup of agricultural carbon emissions attributes to the dramatic development of the agricultural economy as the main factor. As compared with 2001, the lift of agricultural economy level from 2002 to 2016 has triggered carbon delta of 45,204,800 tons, which indicates that as other factors remain constant, the agricultural economy development fuels an average annual growth of 3.016 million tons. carbon emissions. However, the agricultural carbon emissions cannot blindly be reduced at the cost of the agricultural economy development. The way the Xinjiang's economy got developed is to steadily advance agricultural modernization and boost peasants' income. Additionally, it is also required to spur on the constructions for returning cultivated land into forests and grasslands so that we can achieve emission reduction and carbon sinks.

The agricultural labor force is also a factor that expedites the buildup of agricultural carbon emissions in Xinjiang. The expansion in the scale of agricultural labor force in 2002-2016 has contributed to a carbon delta of 9,440,500 tons, which implies that when other factors are constant, the increase in the agricultural labor force has led to an annual increase of 629,400 tons. carbon emissions. According to statistics, the number of agricultural employees in Xinjiang continuously hikes up from 3.879,2 million in 2001 to 5.268,2 million in 2016, at an average annual growth rate of 2.06 %. It is deduced that the majority of farmers choose high-carbon production instead of low-carbon production, there is a tendency to the scale effect of agricultural labor force on carbon emissions.

Table 3: Decomposition of factors affecting agricultural carbon emissions in Xinjiang in 2001-2016

Year	ΔCPF(10^4t)	ΔCSF(10^4t)	ΔCEF(10^4t)	ΔCL(10^4t)	Gross effect(10^4t)
2002	-94.13	2.58	136.60	24.64	69.70
2003	-459.88	-104.33	696.91	37.39	170.09
2004	-32.82	-2.84	130.52	44.38	139.24
2005	-160.77	6.57	252.95	35.19	133.94
2006	-83.31	-3.48	102.54	49.31	65.06
2007	-467.94	7.10	390.91	24.86	-45.06
2008	-539.05	-6.13	42.32	24.69	-478.16
2009	-11.90	2.93	211.61	40.25	242.89
2010	-1090.28	34.10	801.34	68.96	-185.88
2011	63.93	-5.11	-156.05	156.66	59.43
2012	-44.01	5.38	159.84	173.48	294.68
2013	-90.75	0.08	133.53	87.68	130.54
2014	136.97	1.63	132.54	58.23	329.37
2015	-1440.75	-11.79	1472.87	79.65	99.99
2016	-46.24	-0.43	15.65	38.68	7.66
Total	-4360.93	-73.74	4524.08	944.05	1033.49

4. Conclusions and policy proposals

4.1 Conclusions

In 2001-2016, the total carbon emissions from agriculture in Xinjiang showed a three-stage feature of "rise–decline - rise" while maintaining an overall upward trend, but the carbon emission intensity presented a downward trend. Judging from the structure of carbon emissions, livestock breeding and fertilizer input are the major carbon sources.

Xinjiang has a large spatial differentiation in agricultural carbon emissions. Leading industries affect carbon emissions. Judging from the carbon intensity, it features to be "High in the north, low in the south and centered in the east". From the structure of carbon emissions, Urumqi, Bortala, Bayingo land Aksu are the leading planting areas. Kezhou, Altay, Yili, Khotan, and Kumul are the leading areas for livestock husbandry. Changji, Turpan, Karamay, Tacheng, and Kashi are composite areas.

The improvement of agricultural production efficiency and the agricultural industry structure adjustment are conducive to agricultural carbon reduction. The agricultural economy development and the expansion of the agricultural labor force contribute to the growth of agricultural carbon emissions. With the development of the secondary and tertiary industries, and in the context of the urbanization construction, whether the transfer of rural labor force can play a role in carbon emission reduction remains to be further proved.

4.2 Policy proposals

It is encouraged to vigorously develop low-carbon agriculture and stimulate the sustainable development of agriculture. By exploring the development paths of recycling, organic and ecological agriculture, it is favorable to playing the multifunctional role of agriculture in regulating climate and conserving ecology. Reduce emissions by adjusting measures to local conditions and exploit resource advantages of areas. In the leading areas for the planting industry, people should reduce the use of fertilizers and pesticides to a large extent. While in those for animal husbandry people should explore channels for the compound utilization of livestock excrement. Continuously innovate and develop low-carbon production technologies and transform agricultural production modes. To improve the agricultural production efficiency, it is required to depend on the advancement of low-carbon technology.

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