Study on Agricultural Carbon Emission Estimation and Grading Evaluation -- Taking Chengdu as an Example

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Abstract. At present, China is in the stage of agricultural economic transformation and development. It is urgent to regard low-carbon agriculture as the main task of sustainable agricultural development. This paper takes Chengdu as an example to calculate the total carbon emissions and emission intensity of agricultural carbon in the past 2007-2018 years through the carbon emission coefficient method, and to analyze and evaluate the agricultural carbon emission structure and agricultural carbon emission level. Finally, it is concluded that the present situation of agricultural carbon emissions in Chengdu and its dynamic changes in the past ten years will help further clarify the types of agricultural carbon emissions in Chengdu. At the same time, it can also provide theoretical support for the action of energy conservation and emission reduction and the construction of ecological civilization in Chengdu.

Keywords. Agricultural carbon emissions, carbon emission intensity, agricultural carbon sources, low-carbon agriculture.

1. Introduction
In December 2019, the United Nations climate change conference was held in Madrid, and global warming and climate risk have once again become the focus of attention. According to the IPCC in its fifth assessment report (AR5), climate change can be considered to be caused by human activities at 95% confidence level [1]. Climate change will lead to serious damage to the global ecosystem, causing unimaginable impact on the global economy. As the foundation of people's livelihood, agriculture also emits a lot of greenhouse gases. According to data released by FAO in 2014, global greenhouse gas emissions in agriculture have almost doubled over the past fifty years and will increase by 30% by 2050 [2]. Therefore, agricultural carbon emissions are increasingly concerned by all sectors of society.

In formulating the goal of building "two zones" (high standard construction of grain production functional areas and important agricultural production protection zones), Chengdu emphasizes the development of green low-carbon agriculture and implements the strategy of "one control, two reduction" and recycling of agricultural wastes to achieve sustainable and healthy development. At present, the agricultural carbon emission reduction in Chengdu is still in the stage of "addressing the symptoms rather than the root cause", and the source of carbon emission has not been clear, so the research on carbon emission measurement and grade evaluation is of great significance.
2. General Situation of the Study Area
Chengdu is located in the Sichuan Basin (figure 1), with an average altitude of 500 meters. It has plains, hills and high mountains, of which the plain accounts for 36.4%. The climate is subtropical monsoon climate, with annual average temperature about 16 ℃, sunshine hours of 1156.7 hours and annual rainfall of 1000 mm. Chengdu plain is rich in soil nutrients and abundant in water resources. It is known as "the land of abundance", and has superior agricultural production conditions, which has a good foundation for the development of low-carbon agriculture.

Figure 1. Location analysis map of Chengdu.

3. Calculation of Agricultural Carbon Emission

3.1. Data Sources and Calculation Methods

3.1.1. Data Sources. According to the statistical yearbook of Chengdu and the statistical bulletin of national economic and social development of Chengdu from 2007 to 2018, it mainly obtains the data of fertilizer application amount, pesticide use amount, agricultural plastic film use amount, agricultural diesel consumption amount, total power of agricultural machinery, ploughing area and effective irrigation area in Chengdu from 2007 to 2018, in which chemical fertilizer refers to pure amount, and some scattered missing data in years are converted by proportion calculation.

3.1.2. Calculation Methods. There are many studies on agricultural carbon emissions, but the relevant calculation methods have not yet formed a unified. This paper mainly uses the research methods of Li Bo and Tian Yun [3-4]. According to the IPCC guidelines for national greenhouse gas inventories, carbon emission measurement is focused on narrow agriculture, and the main carbon sources are chemical fertilizer, agricultural machinery, agricultural film, agricultural tillage, diesel oil, pesticide and effective irrigation. The calculation formula of total agricultural carbon emission is as follows:

$$ C = \sum C_i = \sum U_i \times \Omega_i $$  \hspace{1cm} (1)

In the formula, $C$ represents total agricultural carbon emissions; $C_i$ is the carbon emission of the $i^{th}$ carbon emission source; $U_i$ is the consumption of the $i^{th}$ carbon source. It includes the amount of chemical fertilizer converted into pure, the amount of pesticide used, the amount of agricultural plastic film used, the amount of agricultural diesel oil used, the total power of agricultural machinery,
Effective irrigation
Ploughing
Agricultural machinery
Agricultural film
Pesticides
Chemical fertilizer
Carbon emission sources

\[ \text{Total carbon emissions} = \sum_i \left( \text{carbon emission coefficient} \times \text{factor carbon emission coefficient} \right) \]

\[ \Omega_i \] refers to the carbon emission coefficient of the main agricultural carbon sources. According to the research of relevant scholars and the actual situation of Chengdu, the carbon emission coefficient of the main agricultural carbon sources is determined as table 1.

Table 1. Carbon emission coefficient of main agricultural carbon sources.

| Carbon emission sources                  | Emission coefficient | Data reference source                                                                 |
|-----------------------------------------|----------------------|---------------------------------------------------------------------------------------|
| Chemical fertilizer (kg CE/kg)          | 0.8956               | ORNL (Oak Ridge National Laboratory) [5]                                             |
| Pesticides (kg CE/kg)                   | 4.9341               | ORNL (Oak Ridge National Laboratory)                                                 |
| Agricultural film (kg CE/kg)            | 5.1800               | IREEA (Institute of agricultural resources and ecology, Nanjing Agricultural University) |
| Diesel oil (kg CE/kg)                   | 0.5927               | IPCC (Intergovernmental Panel on climate change)                                     |
| Agricultural machinery (kg CE/kW)       | 0.1800               | IPCC (Intergovernmental Panel on climate change)                                     |
| Ploughing (kg CE/hm²)                   | 3.1260               | IABCAU (College of Agronomy and biotechnology, China Agricultural University)         |
| Effective irrigation (kg CE/hm²)        | 266.48               | Duan Huaping [6]                                                                     |

3.2. Total Carbon Emissions and Their Changes in Agriculture

According to formula (1) and the carbon emission coefficient of main agricultural carbon sources in table 1, the total agricultural carbon emission and its year-on-year growth rate in Chengdu from 2007 to 2018 are calculated. The conclusion is shown in table 2. Compared with the total amount in 2007, the total agricultural carbon emission in 2018 decreased by 28.22×10³ t, with a reduction ratio of more than 8.19%. The average annual emission during the period was 313.66×10³ t, with an average annual reduction of 0.64%. As shown in figure 2, the agricultural carbon emissions in Chengdu from 2007 to 2018 showed a fluctuating downward trend, and the overall temporal change can be divided into three stages: significant decline-steady slight decline-sudden recovery.

Table 2. Agricultural carbon emissions in Chengdu during 2007-2018. Unit: thousand tons(KT)

| Year    | Chemical fertilizer | Pesticides | Agricultural film | Diesel oil | Agricultural machinery | Ploughing | Effective irrigation | Total carbon emissions | Annual growth rate (%) |
|---------|---------------------|------------|-------------------|------------|------------------------|-----------|----------------------|------------------------|------------------------|
| 2007    | 178.5020            | 32.6440    | 44.8174           | 14.8406    | 0.4600                 | 2.8254    | 70.4040              | 344.4934               | —                      |
| 2008    | 177.2742            | 32.4170    | 44.5117           | 14.7375    | 0.4741                 | 2.8087    | 59.6382              | 331.8585               | -3.6677                |
| 2009    | 165.9860            | 30.1967    | 50.3962           | 15.1731    | 0.5046                 | 2.6135    | 58.2461              | 323.1163               | -2.6343                |
| 2010    | 153.7674            | 29.0964    | 54.6386           | 14.7582    | 0.5187                 | 2.6229    | 57.0694              | 312.4716               | -3.2944                |
| 2011    | 155.4699            | 27.9517    | 54.7422           | 14.9360    | 0.5592                 | 1.2646    | 54.2132              | 309.1368               | -1.0672                |
| 2012    | 141.8254            | 27.1869    | 56.4845           | 14.7582    | 0.5766                 | 1.3030    | 51.7581              | 294.0567               | -4.8781                |
| 2013    | 140.0486            | 26.2395    | 57.2908           | 14.5804    | 0.6160                 | 1.2742    | 49.7705              | 289.8200               | -1.4408                |
| 2014    | 140.0145            | 25.5340    | 50.4558           | 14.6990    | 0.6587                 | 1.3064    | 48.5444              | 291.2127               | 0.4806                 |
| 2015    | 138.7150            | 24.9962    | 62.3776           | 14.4026    | 0.6672                 | 1.3520    | 46.8035              | 289.3140               | -0.6520                |
| 2016    | 166.3676            | 27.5520    | 60.3247           | 20.1518    | 0.7020                 | 1.4525    | 51.6643              | 334.2150               | 15.5198                |
| 2017    | 164.4295            | 26.5356    | 65.9414           | 19.9740    | 0.7269                 | 1.5863    | 48.7906              | 327.9843               | -1.8643                |
| 2018    | 162.2164            | 25.4206    | 65.7238           | 19.7369    | 0.6919                 | 1.4573    | 41.0297              | 316.2765               | -3.5696                |
| Average | 157.0514            | 27.9809    | 56.9891           | 16.0624    | 0.5963                 | 1.8220    | 53.1610              | 313.6630               | -0.6426                |
From 2007 to 2012, the agricultural carbon emission of Chengdu decreased significantly. The total carbon emission decreased from 344.49×10³ t in 2007 to 294.06×10³ t in 2012, with a decrease rate of 50.44×10³ t and a decrease rate of 14.64%. From 2013 to 2015, the total carbon emission of Chengdu showed a steady and slight decrease; there was a significant increase in 2016. The total carbon emissions increased from 289.31×10³ t in 2015 to 334.21×10³ t in 2016, and the growth rate reached 44.9×10³ t in one year, with the growth rate of 15.52%. Since then, the agricultural carbon emissions in Chengdu from 2016 to 2018 have decreased year by year, but the total annual emissions are still greater than the carbon emission levels in 2010-2015. According to figure 2, there was a time node of abrupt change of agricultural carbon emissions in Chengdu in 2016, which was initially regarded as an abnormal value. By analyzing the reasons, it is found that in 2016, Jianyang was included in the administrative division of Chengdu, which increased the impact of a prefecture level city on carbon emissions. Moreover, Jianyang is a strong traditional agricultural county, and the total agricultural carbon emissions far exceeds most of the districts and counties of Chengdu, so it can explain the sudden recovery of the third stage.

![Figure 2. Agricultural carbon emissions and annual growth rate in Chengdu during 2007-2018.](image)

As shown in figure 2, the analysis shows that the annual growth rate of agricultural carbon emissions in Chengdu from 2007 to 2018 shows a downward trend, but the negative value of year-on-year growth is small. It shows that Chengdu explores the development mode of low-carbon agriculture actively, but the current total reduction of agricultural carbon emissions is not significant. Therefore, the sustainable development of low-carbon agriculture in Chengdu still has a large space for improvement.

3.3. Carbon Emission Intensity and Their Changes in Agriculture

In this paper, the carbon emission intensity is selected to measure the carbon emissions in Chengdu. Among them, the concept of carbon emission intensity is defined as the carbon emission per 10000 yuan of crop planting, the unit is t/10000 yuan. According to the total agricultural carbon emissions and the total output value of planting industry, the agricultural carbon emission intensity of Chengdu from 2007 to 2018 is calculated. The conclusions are as follows:

During 2007-2018, the carbon emission intensity of Chengdu showed a gradual downward trend, from 0.18 t/10000 yuan in 2007 to 0.05 t/10000 yuan in 2018, with an average annual emission intensity of 0.11 t/10000 yuan, and the average annual carbon emission intensity decreased by 9.52%. It can be seen from figure 3 that the carbon emission intensity in Chengdu from 2007 to 2018 has been continuously reduced. From 2007 to 2015, the total carbon emission decreased. In 2016, with the
increase of total carbon emission, the carbon emission intensity still showed a downward trend, because the gross output value of planting industry increased significantly. In addition, from the year-on-year growth curve, it can be seen that the annual growth rate of carbon emission intensity in Chengdu has a large change and presents a trend of irregular change, with the slowest decline of -2.19% in 2016. On the contrary, carbon emission intensity decreased the fastest, with an annual growth rate of -18.01% in 2018. The results show that the agricultural production mode has changed and the planting structure has been adjusted in Chengdu during 2007-2018. Especially, the intensity of agricultural carbon emission in recent years, represented by 2018, has decreased significantly, which shows that the governance of agricultural carbon emission in Chengdu has achieved certain results.

Figure 3. Agricultural carbon emission intensity and annual growth rate in Chengdu during 2007-2018.

3.4. Structure and Change of Agricultural Carbon Emission Sources

According to the calculation results of carbon emissions of major agricultural carbon sources in Chengdu from 2007 to 2018, the structure and annual change of agricultural carbon emission are shown in figure 4.

In recent ten years, the carbon emission level of the main agricultural carbon sources in Chengdu maintained a relatively stable state. Among them, chemical fertilizer is the most important carbon source affecting carbon emissions in Chengdu. The annual average carbon emission caused by chemical fertilizer is 157.0514×10^3 t, accounting for 50.07% of the average, which is equivalent to the sum of other carbon sources. Agricultural film, effective irrigation, pesticide and agricultural diesel oil accounted for 18.17%, 16.95%, 8.92% and 5.12%. The carbon emission of tillage and agricultural machinery is the least, both less than 1.00%. As far as the fluctuation range is concerned, the carbon emissions of chemical fertilizer and effective irrigation fluctuated greatly. Due to the promulgation of the action plan for zero growth of fertilizer consumption by 2020 and the obvious decrease of rice planting area, the carbon emissions of the two factors had a significant downward trend.
Figure 4. Agricultural carbon emission structure and its changes in Chengdu during 2007-2018.

4. Evaluation of Agricultural Carbon Emission Level

In order to further analyze the overall level of agricultural carbon emissions in Chengdu, according to the spatial grading standard of agricultural carbon emissions in different provinces and cities [7], we classified the agricultural carbon emissions in different years in Chengdu.

Firstly, the K-S test of a single sample is used to test the normality of the total amount and intensity of agricultural carbon emissions in Chengdu from 2007 to 2018. The results all accept the original hypothesis, and all sequences obey normal distribution. According to the principle of normal distribution, the classification standard is shown in table 3.

Table 3. Space classification criteria of agricultural carbon emissions in China.

| Emission level     | Division basis                                                                 |
|--------------------|--------------------------------------------------------------------------------|
| High emissions     | \( T > (\mu_1 + 0.44\sigma_1) \), \( E > (\mu_2 + 0.44\sigma_2) \)         |
| Medium-High emissions | 1) \( T > (\mu_1 + 0.44\sigma_1) \), \( (\mu_1 - 0.44\sigma_1) < E < (\mu_2 + 0.44\sigma_2) \)      |
|                    | 2) \( (\mu_1 - 0.44\sigma_1) < T < (\mu_1 + 0.44\sigma_1) \), \( E > (\mu_2 + 0.44\sigma_2) \) |
| Medium emissions   | 1) \( (\mu_1 - 0.44\sigma_1) < T < (\mu_1 + 0.44\sigma_1) \), \( (\mu_1 - 0.44\sigma_1) < E < (\mu_2 + 0.44\sigma_2) \) |
|                    | 2) \( (\mu_1 - 0.44\sigma_1) < T < (\mu_1 + 0.44\sigma_1) \), \( E > (\mu_2 + 0.44\sigma_2) \) |
| Medium-Low emissions | 1) \( (\mu_1 - 0.44\sigma_1) < T < (\mu_1 + 0.44\sigma_1) \), \( E < (\mu_2 + 0.44\sigma_2) \) |
|                    | 2) \( (\mu_1 - 0.44\sigma_1) < T < (\mu_1 + 0.44\sigma_1) \), \( E < (\mu_2 - 0.44\sigma_2) \) |
| Low emissions      | \( T < (\mu_1 - 0.44\sigma_1) \), \( E < (\mu_2 - 0.44\sigma_2) \)          |

\( T \): Total agricultural carbon emissions;
\( E \): Agricultural carbon emission intensity;
\( \mu_1 \): Average value of total agricultural carbon emissions;
\( \mu_2 \): Average value of agricultural carbon emission intensity;
\( \sigma_1 \): Standard deviation of total agricultural carbon emission;
\( \sigma_2 \): Standard deviation of agricultural carbon emission intensity.
Table 4. Classification of agricultural carbon emissions in Chengdu during 2007-2018.

| Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Emission level | H    | H    | H    | M-H  | M    | M-L  | L    | L    | M    | M    | M-L  | M-L  |

H: High; M-H: Medium-High; M: Medium; M-L: Medium-Low; L: Low.

According to the table 4, we can know the emission level of agricultural carbon emission in Chengdu from 2007 to 2018. Although the annual distribution of emission levels has some changes, the overall emission level has changed from high to low, and the overall trend is stable to good. In recent years, especially in 2018, Chengdu’s agricultural carbon emissions have been at a low level. This indicates that compared with other cities in China, Chengdu has adjusted the carbon emissions structure, and the development of low carbon agriculture has been improving.

5. Conclusion

By calculating the total amount, intensity and source structure of agricultural carbon emissions, the conclusions are as follows: From 2007 to 2018, the agricultural carbon emissions in Chengdu showed a fluctuating downward trend, which was mainly manifested in three stages: significant decline-steady slight decline-sudden recovery; The intensity of agricultural carbon emission decreased from 2007 to 2018; By analyzing the structure of carbon emission sources, the top three carbon sources were chemical fertilizer, agricultural film and effective irrigation; After discharge classification, the level of agricultural carbon emissions in Chengdu turned from high to low, and the overall trend was stable.

Therefore, it is imperative to adjust the agricultural industrial structure to achieve emission reduction. Reducing the proportion of traditional agriculture, vigorously developing modern and ecological agriculture, improving the multi-function of agricultural production, and further exploring the development mode of low-carbon agriculture with better benefits and less carbon emissions are the current direction of agricultural carbon emission reduction in Chengdu.

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