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Characterization of Carbon Emissions from National Crop Production Based on China Statistical Yearbook Data

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Abstract. This study utilizes the China Statistical Yearbook 2023 as the data basis to explore the temporal and spatial changes of total agricultural carbon emissions and the importance of reducing agricultural carbon emissions to solve the greenhouse effect in the context of China's transition to green and low-carbon agricultural production. This is achieved through statistical analysis and calculations of fluctuations in agricultural output value, cultivated land area, irrigated area, fertilizer application, sown area of crops, and production from 2014 to 2022. The results indicate the following: 1) The total carbon emissions from agricultural land use in China exhibited a trend of initial increase followed by a decrease, reaching a peak of 128.9831 million tons in 2015; 2) Changes in cultivated land area contributed the highest average carbon emissions, followed by fertilizer application, accounting for 45.39% and 38.35% of the average carbon emissions in 2022, respectively; 3) The carbon emission reduction in national crop production is significantly influenced by policies, and controlling the amount of fertilizer use can effectively reduce carbon emissions from national crop production. The research findings provide a theoretical foundation for the transition to green and low-carbon agricultural production.

1 Introduction

As the economy grows, environmental issues caused by the massive greenhouse gases emissions such as CO2 have become one of the key areas of focus for scholars today. Carbon dioxide emissions are divided into natural emissions and anthropogenic emissions. Anthropogenic emissions are resulted from human activities, mainly including fossil fuel consumption, biomass burning, agricultural and forestry production, and animal husbandry [1]. As the world's largest carbon emitter, China’s annual carbon emissions exceed 10 billion tons, accounting for approximately 30% of the global anthropogenic carbon emissions [2,3]. As the world's largest grain producer, China's per capita grain possession reached 474 kg in 2020 [4] and the agricultural carbon emissions accounted for about 17% of the country's total greenhouse gas emissions [5].

Recent years, various policies have been issued worldwide to deal with global warming. In 1992, the United Nations issued the Framework Convention on Climate Change in Rio de Janeiro, Brazil, aiming to stabilize the concentration of greenhouse gases at a level able to prevent dangerous anthropogenic interference with the climate system [6]. In 1997, the Kyoto Protocol was issued [7]. In 2015, the Paris Agreement was reached in 2015, which plans to limit global warming to 1.5oC [8]. In 2020, President Xi officially announced that China projects to peak its carbon dioxide emissions by 2030 and achieve the goal of carbon neutrality by 2060 [9]. During the Climate Leaders Summit of 40 countries held in April 2021, President Xi put forward the "six principles," further strengthening the control of greenhouse gases [10].

Driven by these policies, China’s agricultural carbon emissions have fluctuated significantly. The sources are diverse, mainly including agricultural land use activities such as tillage, fertilization, and irrigation, as well as greenhouse gas emissions from the growth and development of food crops such as rice [11]. Besides, economic development often leads to increased greenhouse gas emissions, and agricultural carbon emission totals and emission intensities are important indicators for measuring carbon emission efficiency [12]. It has been an important research tool for scholars to conduct statistical analysis to reflect the intensification of carbon emissions during agricultural production utilizing public data. However, there are few reports on the latest agricultural public data statistics analyzing total agricultural carbon emissions after 2020.

This study, based on the public data published in the China Statistical Yearbook 2023, explores the patterns and relationships between agricultural and other industrial output values, cultivated land area, irrigated farmland area, chemical fertilizer, sown area of crops, and agricultural carbon emissions from 2014 to 2022. It further endeavors to delve into the impact of policies promoting agricultural carbon neutrality on the economic landscapes of agriculture across diverse regions.

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2. Methods and materials

2.1. Data Sources

The information for this study primarily comes from published literature and the China Statistical Yearbook 2023. The literature search ended on March 8, 2024, with 10 articles selected using the keyword "TS=(carbon neutrality policies AND carbon peak)", 8 articles selected using the keyword "TS=(agricultural carbon emission coefficients and measurements)", 4 articles selected using the keyword "TS=(carbon emissions AND greenhouse effect)", and 6 articles selected using the keyword "TS=(China's carbon neutrality AND food security)". From the China Statistical Yearbook 2023, the following data are extracted: 1) cultivated land area by region (Section 8-20); 2) total output value and index of agriculture, forestry, animal husbandry, and fishery (Section 12-3); 3) irrigated farmland area and agricultural fertilizer application (Section 12-5); 4) sown area of crops (Section 12-8); and 5) main agricultural product output (Section 12-10). The data extraction included average national data for the past nine years and average provincial and municipal data for the latest year.

2.2. Statistical methods

In this study, the public data from the sources mentioned in Section 2.1 were transcribed into Excel using WPS (WPS Office 12.1.0, Beijing Kingsoft Office Software Co., Ltd., Beijing, China) for data analysis and chart preparation.

Four key indicators, namely cultivated land area, chemical fertilizer, agricultural irrigation, and turnover, were selected to calculate the total carbon emissions from crop production inputs (Carbon Emission, CE/E) [13]. The calculation formula is shown in (1). In the formula, E is the total agricultural carbon emissions; Ei refers to the carbon emissions from various sources; Ti denotes the quantity of each carbon emission source; and δi means the carbon emission coefficient for each source (Table 1).

$$E = \sum Ei = \sum Ti \cdot \delta i \qquad (1)$$

Table 1. Carbon emission coefficient of various inputs in agricultural production process.

Input Factor	**Carbon Emission Coefficient**	**Reference Source**
Cultivated Area	0.0422 $kg\cdot(m^2\cdot a)^{-1}$	Yuan Xiao.et al (2018)[14]
Chemical Fertilizer	0.8956 $kg(C)\cdot kg^{-1}$	Oak Ridge National Laboratory (2009) [15,16]
Agricultural Irrigation	266.48 $kg\cdot km^{-2}$	Duan Huaping.et al (2011)[17]
Turn Over	312.6 $kgC\cdot km^{-2}$	Wu Fenlin.et al (2007)[18]

2.3. Data analysis

In this study, WPS-Excel software was applied for the analysis of the trend changes in agricultural data, such as the changes in the proportion of some output values in the total output value, the relationship between cultivated land area and agricultural fertilizer application in different regions, and the proportion and changes in the output of different agricultural products in various regions.

3. Results

3.1. Changes in the Output Value of China's Agriculture, Forestry, Animal Husbandry, and fishery Industries in Recent Years

From 2017 to 2022, the total output value of China's agriculture, forestry, animal husbandry, and fishery sectors increased year by year (Fig. 1a), with a growth rate of 42.7%. The highest growth rate occurred between 2019 and 2020. The proportion of agricultural output value exceeded 50% of the total output value every year, with the agricultural output value in 2022 increasing by 45.4% compared to 2017. The index tended to be stable, and the indices of various industries were relatively close (Fig. 1b).

Fig 1. Absolute value (RMB 100 million) and index (last year =100) of total output value of agriculture, forestry, animal husbandry and fishery in China from 2017 to 2022. (a) and (b) represents the absolute value of gross product and the gross product index.

The distribution of the total output value of China's four major industries varied significantly among provinces (Fig. 2). The top five provinces in terms of total output value were Shandong, Henan, Sichuan, Hubei, and Guangdong. Among them, the top three in terms of agricultural output value were Henan (694.83 billion yuan), Shandong (620.65 billion yuan), and Sichuan (552.88 billion yuan), while the last three were Shanghai (14.93 billion yuan), Beijing (12.98 billion yuan), and Xizang (12.1 billion yuan). The provinces with the highest proportion of non-agricultural output and their respective proportions were Jilin (46.1% for animal husbandry), Xizang (51.5% for animal husbandry), and Qinghai (53.4% for animal husbandry).

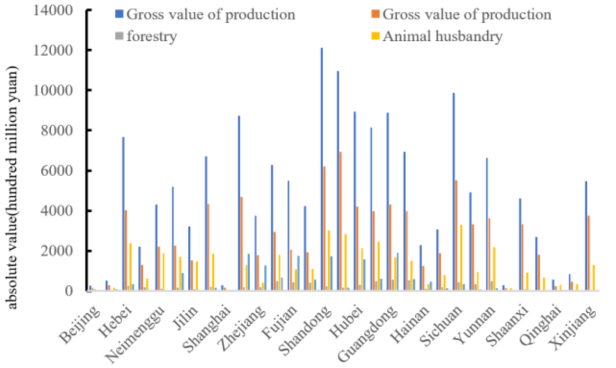


Fig 2. Absolute value of total output value of agriculture, forestry, animal husbandry and fishery in 31 provincial-level administrative regions in 2022 (100 million yuan) of China.

3.2. Changes in China's Cultivated Land Area in Recent Years

Between 2014 and 2021, China's total cultivated land area decreased yearly, with only a slight increase witnessed in 2021-2022 (Fig. 3a). The largest decrease occurred from 2019 to 2017, reaching 5.2%. In 2022, the top three provinces in terms of the proportion of national cultivated land area were Heilongjiang (171.313 million hectares), Inner Mongolia (115.611 million hectares), and Henan (75.349 million hectares) (Fig. 3b). Divided by region, the ranking was as follows: Northeast China (297.323 million hectares) > North China (219 million hectares) > East China (211.986 million hectares) > Northwest China (170.376 million hectares) > Southwest China (161.542 million hectares) > Central China (158.871 million hectares) > South China (56.703 million hectares).

Seven geographical divisions of China in (b) are: Northeast, North, Northwest, East, Central, South and Southwest. The northeast region includes Heilongjiang, Jilin and Liaoning provinces; North China includes Beijing, Tianjin, Hebei and Shanxi provinces and Inner Mongolia Autonomous Region; Northwest China includes Shaanxi, Gansu, Qinghai provinces, Ningxia Hui Autonomous Region and Xinjiang Uygur Autonomous Region; East China includes Shandong, Jiangsu, Shanghai, Zhejiang, Anhui, Fujian, Jiangxi and Taiwan provinces; Central China includes Henan, Hubei and Hunan provinces; South China includes Guangdong Province, Guangxi Zhuang Autonomous Region, Hainan Province, Hong Kong Special Administrative Region and Macao Special Administrative Region; The southwest includes Chongqing Municipality, Sichuan Province, Guizhou Province, Yunnan Province and the Tibet Autonomous Region. (a) includes Hong Kong, Macao and Taiwan, meanwhile (b) does not.

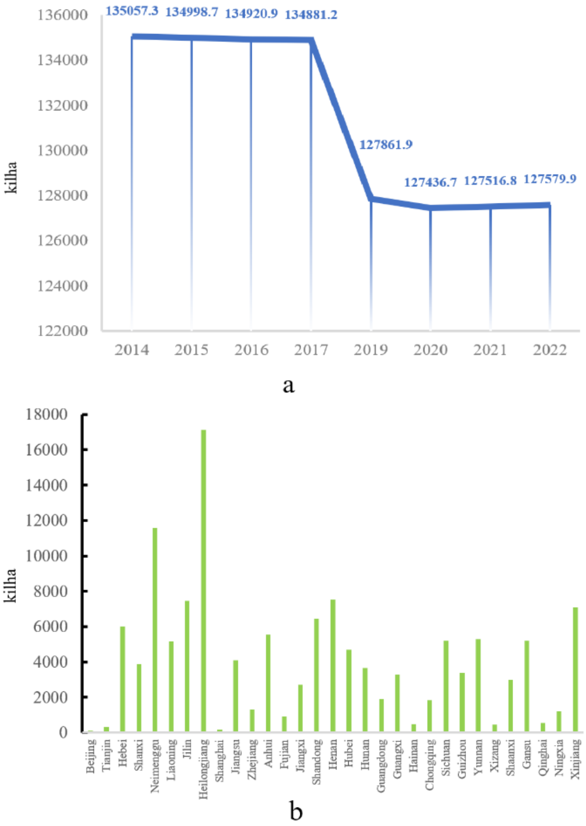
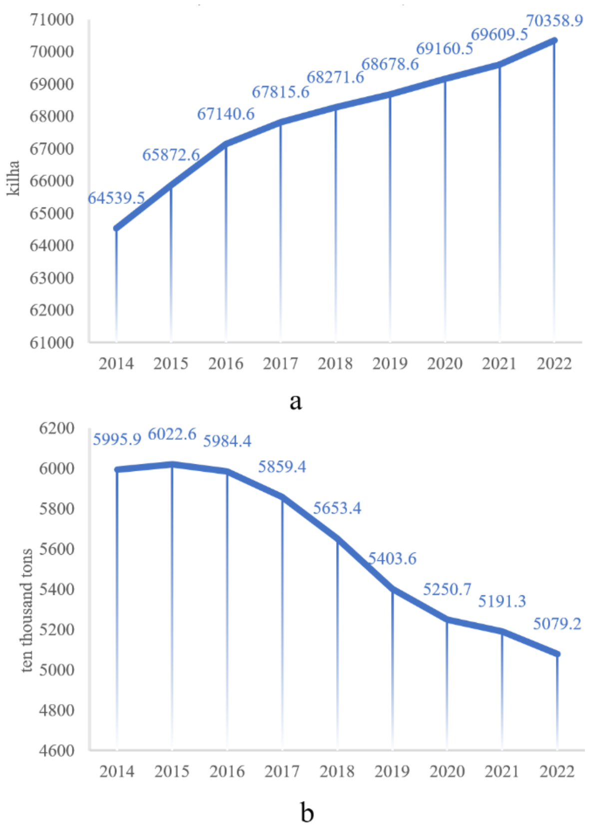


Fig 3. Total cultivated land area from 2014 to 2022 (thousand hectares) and the cultivated land area of 31 provincial administrative regions in 2022 (thousand hectares) of China. (a) and (b) represents the total cultivated land area and the cultivated land area of each province.

3.3. Changes in China’s Irrigated Farmland Area and Agricultural Fertilizer Application in Recent Years

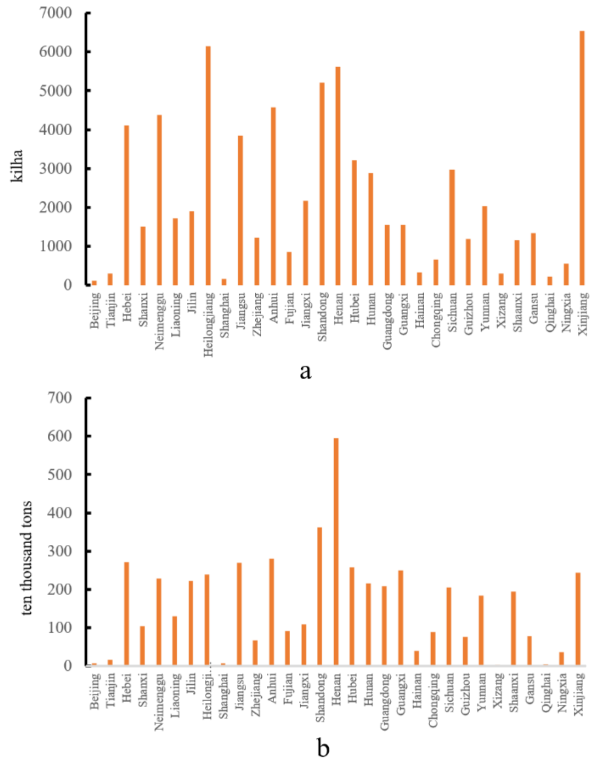
Between 2014 and 2022, the irrigated farmland area of China's cultivated land increased yearly (Fig. 4a). Compared to 2014, the irrigated farmland area in 2022 increased by 5819.4 thousand hectares, with the largest growth occurring from 2015 to 2016, reaching 1.9%. In 2022, the top five provinces of irrigated farmland area were Xinjiang (6534.7 thousand hectares), Heilongjiang (6152.9 thousand hectares), Henan (5623.2 thousand hectares), Shandong (5209.1 thousand hectares), and Anhui (4576.2 thousand hectares) (Fig. 5a). The regional ranking was as follows: East China (18045.7 thousand hectares) > Central China (11708.0 thousand hectares) > North China (10390.3 thousand hectares) > Northwest China (9828.4 thousand hectares) > Northeast China (9776.0 thousand hectares) > Southwest China (8332.3 thousand hectares) > South China (3439.8 thousand hectares).



a

b

Fig 4. Irrigated farmland area (thousand hectares) and agricultural fertilizer application amount (ten thousand tons) in China from 2014 to 2022. (a) and (b) represents irrigated area and fertilizer application.



a

b

Fig 5. Irrigated farmland area (thousand hectares) and agricultural fertilizer application amount (ten thousand tons) in 31 provincial-level administrative regions of China in 2022. (a) and (b) represents irrigated area and fertilizer application.

As for fertilizer application, there was a slight increase from 2014 to 2015, followed by a year-on-year decline from 2015 to 2022 (Fig. 4b). Compared to 2014, the application of agricultural fertilizer decreased by 15.3% in 2022, with the largest decrease occurring from 2018 to 2019, reaching 4.4%. The provinces with the highest agricultural fertilizer application were Henan (5.953 million tons), Shandong (3.621 million tons), Anhui (2.802 million tons), Hebei (2.716 million tons), and Jiangsu (2.701 million tons) (Fig. 5b). The regional ranking was as follows: East China (11.588 million tons) > Central China (10.692 million tons) > North China (6.246 million tons) > Northeast China (5.917 million tons) > Southwest China (5.547 million tons) > Northwest China (5.566 million tons) > South China (4.965 million tons).

3.4. Changes in China's Sown Area of Crops and Production in Recent Years

a

b

Fig 6. Total sown area of crops and grain crops from 2014 to 2022 (thousand hectares) and specific sown area of grain crops from 2017 to 2022 (1000 hectares) in China. (a) and (b) represents the sown area of crops and the sown area of food crops, specifically the sown area of food crops.

Between 2014 and 2022, China's total sown area of crops and grain crops exhibited a gentle trend of change (Fig. 6a). The annual crop planting area exceeded 165,000 thousand hectares, and the sown area of grain crops exceeded 115,000 thousand hectares. From 2017 to 2022, among the sown area of grain crops in China, cereals had the highest area, while potatoes had the lowest (Fig. 6b). In terms of production, the output of major crops in China remained stable from 2017 to 2022 (Fig. 7a). Among them, grain production held the highest proportion, exceeding 50% of the total production of major crops in each year. Fruits were the second largest contributor, with a production of 312.962 million tons in 2022. From 2017 to 2022, grain production first experienced had the highest proportion of grain production, and potatoes followed.

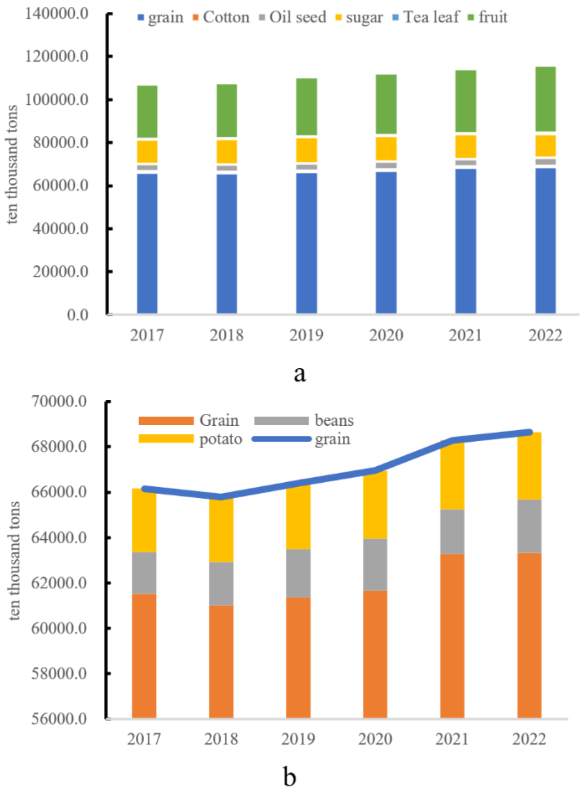


Fig 7. Production of major crops (10,000 tons) and grain production (10,000 tons) in China, 2017-2022. (a) and (b) represents major crop yields and food production.

3.5. Changes in China’s Total Agricultural Carbon Emissions in Recent Years

Table 2. National agricultural land use carbon emissions in China from 2014 to 2022 (104tCO2-eq).

Years	Agricultural irrigation	Fertilizer application	Plowland	Turn over	Total
2014	1719.85	5369.93	5699.42	51.64	12840.84
2015	1755.37	5393.84	5696.95	52.15	12898.31
2016	1789.16	5359.63	5693.66	52.19	12894.64
2017	1807.15	5247.68	5691.99	52.00	12798.82
2018	1819.30	5063.19		51.86	
2019	1830.15	4839.46	5395.77	51.87	12117.26
2020	1842.99	4702.53	5377.83	52.36	11975.71
2021	1854.95	4649.33	5381.21	52.73	11938.22
2022	1874.92	4548.93	5383.87	53.14	11860.86

Note: Data for 2018 are not shown in China Statistical Yearbook 2023.

Between 2014 and 2022, the total carbon emissions from agricultural land use in China first increased and then decreased (Table 2). The peak occurred in 2015, with emissions reaching 128.9831 million tons. Since 2016, the total carbon emissions have decreased yearly, reaching 118.6086 million tons in 2022, decreasing by10.3745 million tons compared to the peak value. The largest decrease occurred from 2017 to 2019, with a reduction of 5.3%.

4. Discussion

4.1. Spatial and Temporal Changes in the Output Value and Index of Agriculture, Forestry, Animal Husbandry, and Fishery in China

The results of this study indicate that the total output value of China's four industries has been steadily increasing in recent years. However, significant regional differences exist, with Henan, Shandong, and Sichuan provinces having high total output values, while Shanghai, Beijing, and Xizang having relatively lower values. These differences can be attributed to two main factors: 1) in terms of total cultivated land area, Henan, Shandong, and Sichuan provinces all have over 55 million hectares of farmland, making them traditional agricultural provinces with high total output values; Beijing and Shanghai, as municipalities directly under the central government, have small total and cultivated land areas, with an average cultivated land area of less than 250,000 hectares, resulting in low agricultural contributions; Xizang, while being the second-largest province in terms of area after Xinjiang, has an average altitude of over 4,000 meters, limiting the availability of cultivable land. Coupled with a small total population (approximately 3.44 million) and few agricultural workers, Xizang ranks last in agricultural output value. 2)in terms of climate, Henan and Shandong mainly have a temperate monsoon climate, while Sichuan and Shanghai have a subtropical monsoon climate. A small portion of Sichuan and Xizang belongs to a plateau alpine climate. Both the temperate and subtropical monsoon climates are suitable for crop growth, while the plateau alpine climate, due to its high altitude and low temperatures, is not conducive to crop growth.

4.2. Spatial and Temporal Changes in China's Agricultural Cultivated Land Area, Irrigation Area, and Fertilizer Input

Between 2014 and 2022, the top three provinces in terms of cultivated land area in China were Heilongjiang, Inner Mongolia, and Henan, benefiting from favorable land conditions and policy support. Heilongjiang, located in the Northeast Plain, has fertile black soil rich in organic matter and nutrients. Since 1980, China has been engaging in large-scale reclamation of wasteland in the Northeast. In 2017, the *Outline of the Northeast Black Soil Protection Plan (2017-2030)* was proposed to improve soil quality and increase cultivable land area. Inner Mongolia is mainly composed of plateaus, and in recent years, China has been constructing high-standard farmland in the region. With the *Inner Mongolia Autonomous Region Rural Revitalization Strategic Plan (2018-2022)* proposed in 2018, the cultivated land area increased by 24% from 2017 to 2019. Henan, with its unique geographical conditions and natural environment, has always been an important agricultural and grain-producing province in China.

Recent years have seen a decline in China's cultivated land area due to various factors. The rapid economic development has led to the gradual occupation of farmland by industrial, road, and residential land. The increasing number of rural migrant workers has also resulted in a significant amount of abandoned farmland. Additionally, to meet the needs of environmental protection, the country has launched policies to return farmland to forests and grasslands. Despite this, China's irrigated farmland area has been rising. The continued warming of the global climate has led to an increase in China's annual average temperature by 0.5℃ to 0.8℃ compared to the early 20th century[19]. This global warming has caused severe droughts in some regions, making normal precipitation insufficient for crop growth, thus necessitating an increase in irrigation areas. Technological advancements and policy support have contributed to the year-on-year decline in fertilizer application in China. With the development of agricultural technology, more high-quality crop varieties have been cultivated. Currently, precision agricultural techniques are widely used, allowing for targeted fertilization based on soil conditions, precise regulation of fertilizer usage, and cost savings. China has placed increasing emphasis on environmental protection, promoting organic agriculture and green planting practices. For example, the *Action Plan for Substituting Chemical Fertilizers with Organic Fertilizers in Fruit, Vegetable, and Tea Production* was issued in 2017[20], and local governments have implemented organic fertilizer subsidy policies to incentivize farmers to use organic fertilizers. These measures have contributed to the decrease in fertilizer usage.

4.3. Annual Changes in the Sown Area of Crops and Production, as well as Total Carbon Emissions from Agricultural Land Use in China

In recent years, China has witnessed minimal changes in its sown area of crops, with grain production accounting for over half of the total agricultural output. However, between 2017 and 2018, China's grain production declined by 371.5 tons, primarily due to two factors: firstly, the sown area of grain crops decreased from 117,989 thousand hectares in 2017 to 117,037 thousand hectares in 2018; secondly, persistent rainy weather in southern regions affected rice harvesting in some parts of Jianghuai, which in turn impacted wheat planting. In 2020, the Chinese Communist Party Central Committee, in its *Suggestions on Formulating the 14th Five-Year Plan for National Economic and Social Development and the Long-term Goals for 2035*, officially included the grain security strategy into the five-year plan for the first time, emphasizing the strengthening of functional areas for grain production, important agricultural product protection zones, and areas with distinct advantages in specific agricultural products. This measure has provided a solid foundation for the steady growth of grain production in the future [21].

According to statistical data from this study, the total carbon emissions from China's agricultural sector have been decreasing year by year, Especially since 2017, the total carbon emissions began to drop sharply, playing a key role in the reduction of arable land and the reduction of fertilizer application. The reduction of arable land has a positive effect on reducing carbon dioxide emissions without affecting crop yields. Fertilizer has been identified as a factor influencing agricultural carbon emissions [22]. To reduce carbon emissions caused by agricultural fertilizer application and mitigate harmful effects of fertilizer on soil, the Ministry of Agriculture issued the *Action Plan for Zero Growth in Fertilizer Usage by 2020* in 2015 [23]. This plan focuses on the goal of green agriculture, promoting in-depth actions to reduce fertilizer use and increase efficiency, thereby continuously enhancing fertilizer utilization rate. This reduces the production costs of agricultural operations and significantly decreases carbon emissions associated with fertilizer application. Notably, when fertilizer application is reduced, grain yield per unit area does not necessarily decrease [24]. Moreover, the substitution of organic fertilizer for chemical fertilizer has led to significant improvements in soil physicochemical properties, including reduced soil bulk density, adjusted soil pH, and enhanced soil fertility. With better crops, carbon dioxide emissions are also significantly lower.

5. Conclusion

Despite a gradual decline in China's cultivated land area, agricultural output has been increasing annually. With technological advancements, China has been expanding its irrigated farmland and replacing chemical fertilizers with organic fertilizers. The decrease in fertilizer application has significantly reduced the total carbon emissions from agriculture. While ensuring a stable sown area of crops and a yearly increase in grain production, China has also continuously reduced agricultural carbon emissions. The results of this study play a positive role in promoting sustainable and low-carbon agricultural production and make a great contribution to the development of carbon neutrality. Relevant agricultural policies can also be appropriately adjusted according to this study.

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