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Study on Agricultural Green Total Factor Productivity around Dongting Lake

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Abstract: At present, the new development trend of our economy has been transformed into green sustainable development. Agriculture is a basic industry of the country, and it is an important revolution in the concept of agricultural development to promote the development of green agriculture. Under the constraint of carbon emission, the overall characteristics and regional characteristics of agricultural green total factor productivity were analyzed in order to provide reference for agricultural green development in the area around Dongting Lake. Based on the panel data of three counties and cities around the Dongting Lake area from 2012 to 2021, this paper adopted six types of major carbon emission sources to measure the agricultural carbon emissions around the Dongting Lake area, and took the measured agricultural carbon emissions as the index of non-expected output, and used the non-radial and non-angular super efficiency SBM model to measure the agricultural green total factor productivity around the Dongting Lake area. The results showed that: (1) The total agricultural carbon emission around Dongting Lake was in a state of decline from 2012 to 2021, and its year-on-year growth rate was negative from 2016 to 2021. (2) During the study period, the agricultural green total factor productivity in the Dongting Lake area showed a flattening, declining and rising trend, and the agricultural green total factor productivity was relatively high. Based on this, efforts can be made in the following aspects to further reduce agricultural carbon emissions and low-carbon agricultural road around Dongting Lake District: increase financial support, improve the utilization efficiency of agricultural materials, strengthen the investment of scientific and technological funds and improve agricultural technology.

1. Introduction

As the contradiction between regional economic development and resources and environment is increasingly acute, improving resources and environmental efficiency is one of the inherent requirements for China to enter the high-quality development stage, and the establishment of a modernization pattern of harmonious coexistence between man and nature and a green, low-carbon circular development system. The key to the construction of green development with high technology content, low resource consumption and less environmental pollution[1] lies in the improvement of green total factor productivity, which is the economic development efficiency after considering resource input and environmental cost on the basis of green development concept[2].

Dongting Lake District plays an important role in the development of agricultural economy in Hunan Province, and is also the center of coordinated economic development in central China, shouldering the heavy responsibility of ecological security and coordinated and sustainable development in the Yangtze River Basin[3]. With the intensive, large-scale and industrialized development of the lake area agriculture and the increasing number of agricultural products, the agricultural input has been increased year by year, and the agricultural comprehensive production capacity has been significantly enhanced. However, the abuse of chemical inputs such as fertilizers, pesticides and agricultural film has become the main source of ecological environment deterioration and agricultural product insecurity in the lake area. In order to implement the concept of sustainable agricultural development, it is necessary to incorporate environmental factors into the accounting system to measure agricultural green total factor productivity, that is, to calculate agricultural green total factor productivity[4].

At present, scholars consider the impact of resources and environment on productivity when measuring economic development, which has developed modern economic growth theory to a certain extent. Pittman[5] (1983) tried to incorporate environmental factors into the total factor productivity measurement model for the first time, taking pollution control cost as "undesirable output" to measure the efficiency of paper mills in Wisconsin, USA. In recent years, many scholars have used stochastic frontier production function (SFA) and data enveloping analysis (DEA) to estimate China's agricultural total factor productivity and agricultural green total factor productivity in different periods based on the perspective of resource and environmental constraints. Tone[6] (2001) et al. proposed the SBM model on the basis of the traditional DEA in a pioneering way. This model is the most commonly used non-radial and non-angular distance function at present, which can avoid the shortcomings of traditional measurement methods. Oh[7] (2010) constructs GML productivity index to solve the problem of non-transitivity of generalized ML index and non-solution of linear programming, which has been widely used in the academic circle. Ge Pengfei and Tian Wei et al.[8] took carbon emission as an environmental index, and used the SBM model of undesirable output and the Luenberger index based on SBM-DDF respectively to measure China's agricultural environmental efficiency and agricultural green total factor productivity. Xiao Rong[9] (2018) established a model to estimate agricultural green total factor productivity in Hunan Province and its 14 cities based on directional distance function and Malmquist-Luenberger productivity index. Based on the accounting of agricultural non-point source pollution, Lv Na[10] (2019) used the non-radial and non-angle SBM super efficiency model containing non-expected output and Malmquist index to estimate the agricultural environmental technical efficiency and agricultural green total factor productivity during the 12th Five-Year Plan period. Du Hongmei[11] (2020) studied 21 counties (cities and districts) in Dongting Lake from 1995 to 2016, and combined with SE-SBM model and Malmquist index, measured and analyzed agricultural GTFP around Dongting Lake and its temporal evolution characteristics, regional differences and convergence. Huang Xiuquan[12] (2020) applied the non-radial and non-angular SBM model and combined with the GML productivity index to analyze the agricultural green total factor productivity of China's provinces (municipalities and autonomous regions) during 1998-2016.

Existing relevant literature has studied all aspects of green total factors, including calculation methods, index selection, calculation result decomposition and so on. Foreign literature in the empirical research, measurement methods and theoretical in-depth research. Domestic literature is almost based on empirical evidence, and the measurement methods are mostly adopted in foreign literature. Meanwhile, existing researches are mostly focused on industry and manufacturing, while there are few researches on agriculture. Moreover, researches on agricultural green total factor productivity are mostly concentrated at the national and provincial levels, while researches on municipal regions are few. Especially, there is little research on agricultural green total factor productivity in Dongting Lake area.

Based on the above literature review, this study adopted the non-radial and non-angular super efficiency SBM model, and took agricultural carbon emission as the non-expected output to comprehensively evaluate the agricultural green total factor productivity in the Dongting Lake region under the carbon emission constraints from 2012 to 2021. Thus, it can provide scientific basis and reference for agricultural low-carbon development path, energy saving and emission reduction and economic sustainable development of Dongting Lake area.

2. Research Methods and Data Sources

2.1 Agricultural Carbon Emission Measurement Methods

Through literature review, it can be concluded that agricultural carbon sources are mainly: first, carbon emissions directly or indirectly caused by the use of chemical fertilizers, pesticides, agricultural film and other agricultural materials; Secondly, diesel oil and electricity consumed when agricultural machinery is used in agricultural production will cause carbon emissions when agricultural irrigation is used[13]. Third, the loss of organic carbon is caused by the destruction of the surface layer of soil when ploughing to make the land more fertile.

Combined with existing studies and according to the greenhouse gas emission method provided in IPCC2006 National Greenhouse Gas Inventory Guide[14], this paper selected agricultural film, fertilizer, tillage area, pesticide, agricultural irrigation area and agricultural diesel as agricultural carbon emission sources around Dongting Lake District, and built the agricultural carbon emission calculation model around Dongting Lake District on this basis:

$$C = \sum C_i \times \delta_i \tag{1}$$

In Formula (1), C is the total agricultural carbon emissions, C_i is the carbon emissions emitted by the ith agricultural carbon emission source, and δ_i is the carbon emission coefficient to be emitted by the ith agricultural carbon emission source[15]. The carbon emission coefficients of the above six types of carbon sources are shown in Table 1.

Table 1: Carbon emission coefficients and sources of various agricultural carbon emission sources

Various sources of carbon emissions	Carbon emission coefficient	Reference data source
Chemical fertilizer (kgC/kg)	0.8956	Oak Ridge National Laboratory
Agricultural film (kgC/kg)	5.18000	Institute of Agricultural Resources and Ecological Environment, Nanjing Agricultural University
Pesticide (kgC/kg)	4.93410	Oak Ridge National Laboratory
Diesel oil (kgC/kg)	0.5927	The United Nations Intergovernmental Panel on Climate Change
Ploughing (kgC/kg)	312.6000	College of Agronomy and Biotechnology, China Agricultural University
Irrigation (kgC/kg)	266.48	Duan Huaping et al[14]

2.2 Super Efficient SBM Model

Data Envelopment analysis (DEA) is a non-parametric efficiency analysis method first proposed by Charnes et al. It can evaluate the relative efficiency of multiple decision units (DMUs) with multi-input and multi-output, and it does not need to build a function model to avoid subjective factors in the expression of input-output relationship. However, the traditional DEA model cannot measure the influence of relaxation variables on environmental efficiency, so the efficiency value of decision making unit may be overestimated, resulting in inaccurate measurement results. Moreover, multiple DEA effective units often appear, and it is impossible to further compare and analyze the effective units of DEA. Therefore, on the basis of the traditional DEA model, in order to solve the problem of measurement error brought by it, Tone proposed a non-radial and non-oriented SBM data envelopment analysis model based on relaxation variables. Considering that the traditional SBM model is unable to distinguish and rank multiple effective DUs, Tone proposes a non-radial and non-angular super efficient SBM model on this basis, which not only avoids the deviation caused by choosing the radial and Angle, but also further evaluates the effective units. In practical application, each region is regarded as a decision unit (DMU), and its mathematical expression is as follows:

$$\mathrm{Min}\rho = \frac{\frac{1}{m}\sum_{i=1}^{m}(\frac{\bar{x}}{x_{ik}})}{\frac{1}{s_1+s_2}(\frac{\sum_{p=1}^{s_1}\overline{y^d}}{y_{pk}^{d}}+\frac{\sum_{q=1}^{s_2}\overline{y^u}}{y_{qk}^{u}})} \tag{2}$$

$$\begin{cases} \bar{x} \geq \sum_{j=1,\neq k}^{n} x_{ij}\lambda_j; \overline{y^d} \leq \sum_{j=1,\neq k}^{n} y_{pj}^{d}\lambda_j; \overline{y^u} \geq \sum_{j=1,\neq k}^{n} y_{qj}^{d}\lambda_j; \bar{x} \geq x_k; \overline{y^d} \leq y_k^d; \overline{y^u} \geq y_k^u \\ \lambda_j \geq 0, i = 1,2,\cdots,m; j = 1,2,\cdots,n, j \neq 0; p = 1,2,\cdots,s_1; q = 1,2,\cdots,s_2 \end{cases} \tag{3}$$

Where, n represents the number of DMU in decision making unit, and each DMU is composed of input m, expected output s_1 and unexpected output s_2. x represents the elements in the input matrix, y_{pk}^{d} represents the elements in the expected output matrix, y_{qk}^{u} represents the elements in the non-expected output matrix, and λ represents the coefficients of the corresponding input or output elements. ρ is the green development efficiency value, the greater ρ, the higher efficiency.

2.3 Data Source and Index Selection

Table 2: Description of input-output variables

Index	Variable	Variable specification
Input index	Labor input	Agricultural employees (10,000)
	Land input	Total sown area of crops (thousands of hectares)
	Mechanical input	Total power of agricultural machinery (10,000 kW)
	Fertilizer input	Agricultural fertilizer application amount (ten thousand tons)
	Irrigation input	Effective irrigated area (thousands of hectares)
	Agricultural plastic film input	Agricultural plastic film usage (10,000 tons)
Expected output index	Gross agricultural output value	Gross product of primary industry (RMB 100 million)
Indicators of undesirable output	Agricultural carbon emission	Agricultural film, pesticides, agricultural diesel, fertilizer, irrigated area and plowing area (10,000 tons)

In this paper, the relevant data of input, expected output and non-expected output indexes in Dongting Lake area during 2012-2021 were used to measure the agricultural green total factor productivity. Among them, the non-desired output is measured by the agricultural carbon emissions estimated by agricultural film, pesticide, agricultural diesel, chemical fertilizer, irrigated area (represented by effective irrigated area) and ploughing area (represented by total sown area) in the area around Dongting Lake. Based on the availability and completeness of the data, the data used in this paper are mainly from the Statistical Yearbook of Hunan Province, China Rural Statistical Yearbook and Hunan Rural Statistical Yearbook from 2013 to 2022.

Based on the current research on the input-output index system of agricultural green total factor productivity, this paper selects six types of input indicators and two types of output indicators, the specific indicators are shown in Table 2.

3. Empirical Analysis

3.1 Analysis of Calculation Results of Agricultural Carbon Emissions Around Dongting Lake

Table 3: Carbon Emissions from Agriculture around Dongting Lake from 2012 to 2021 (Unit: 10,000 tons)

Year	pesticide	Agricultural film	Agricultural diesel oil	Chemical fertilizer	Effective irrigated area (thousands of hectares)	Ploughing area (km^2)	Total agricultural carbon emissions (10,000 tons)	Year-on-year growth rate
2012	18.33	15.33	10.81	270.82	23.34	0.87	339.50	
2013	18.67	15.54	11.39	274.29	23.40	0.86	344.14	1.37%
2014	19.26	15.91	11.83	275.87	27.12	0.88	350.87	1.95%
2015	19.92	16.58	11.85	276.87	27.14	0.90	353.25	0.68%
2016	20.01	16.41	12.01	275.21	27.18	0.91	351.72	-0.43%
2017	19.31	16.40	12.24	269.74	27.23	0.91	345.83	-1.68%
2018	18.16	16.59	12.25	262.12	27.28	0.91	337.33	-2.46%
2019	17.38	16.53	12.31	258.31	27.29	0.79	332.62	-1.40%
2020	16.60	16.47	12.36	254.50	27.76	0.77	328.46	-1.25%
2021	13.84	15.74	12.34	223.21	27.84	0.77	293.73	-10.57%

According to Formula (1), the carbon emissions and total carbon emissions of each agricultural carbon source and the proportion of each carbon source in total agricultural carbon emissions around Dongting Lake District during 2012-2021 were calculated in this paper. Detailed data are shown in Table 3 and Table 4. According to the statistical data of emissions of various agricultural carbon sources and their proportions in the surrounding Dongting Lake region, the annual carbon emissions of chemical fertilizers are more than 2 million tons, with the highest reaching 2,768,700 tons in 2015, and the proportion of chemical fertilizers in agricultural carbon emissions is more than 76%. Although there was an obvious continuous decline from 2012 to 2021 (from 79.77% to 75.99%, a decrease of nearly 4 percentage points), it did not affect its status as the first among the six major carbon emission sources. The second is the area of effective irrigation. In recent 10 years, the annual carbon emission of irrigation is about 230,000 to 280,000 tons. The proportion of carbon emission caused by irrigation is not higher than that of chemical fertilizer, but it is still relatively higher than other emission sources, about 8%. Moreover, pesticide, agricultural film and agricultural diesel, three carbon emissions in the middle, pesticide carbon emissions average about 180,000 tons, the proportion of total carbon emissions average about 5.4%, agricultural film for about 160,000 tons, the proportion of average about 4.8%, agricultural diesel for about 110,000 tons, the proportion of average about 3.6%; Finally, ploughing caused the least carbon emissions, only about 0.25% on average.

It can also be clearly seen from Table 4 that from 2012 to 2021, carbon emissions caused by agricultural film increased from 4.52% to 5.36%, effective irrigation area from 6.88% to 9.48% and agricultural diesel fuel from 3.19% to 4.2% in the area around Dongting Lake. Increased by 0.84 percentage points, 2.6 percentage points and 1.01 percentage points respectively, while the share of carbon emissions caused by pesticides and fertilizers decreased by 0.69 percentage points and 3.78 percentage points respectively. This is mainly related to the popularization of modern agricultural technology.

Table 4: Proportion of agricultural carbon emission sources in total carbon emissions around Dongting Lake Area from 2012 to 2021

Year	Pesticide	Agricultural film	Agricultural diesel oil	Chemical fertilizer	Effective irrigated area (thousands of hectares)	Ploughing area (km^2)
2012	5.40%	4.52%	3.19%	79.77%	6.88%	0.26%
2013	5.42%	4.51%	3.31%	79.70%	6.80%	0.25%
2014	5.49%	4.53%	3.37%	78.63%	7.73%	0.25%
2015	5.64%	4.69%	3.36%	78.38%	7.68%	0.25%
2016	5.69%	4.66%	3.42%	78.24%	7.73%	0.26%
2017	5.58%	4.74%	3.54%	78.00%	7.87%	0.26%
2018	5.38%	4.92%	3.63%	77.71%	8.09%	0.27%
2019	5.23%	4.97%	3.70%	77.66%	8.20%	0.24%
2020	5.05%	5.02%	3.76%	77.48%	8.45%	0.23%
2021	4.71%	5.36%	4.20%	75.99%	9.48%	0.26%

In addition, according to Figure 1, it can be clearly seen that the total agricultural carbon emission around Dongting Lake region is in a process of continuous decline. In addition to the positive year-on-year growth rate of the total agricultural carbon emission in 2013, 2014 and 2015, since 2016, Until 2021, the year-on-year growth rate of agricultural carbon emissions continued to decline to negative and reached -10.57% in 2021. This shows that the carbon emissions in the Dongting Lake area are continuously reduced, and the agricultural green development is in good shape.

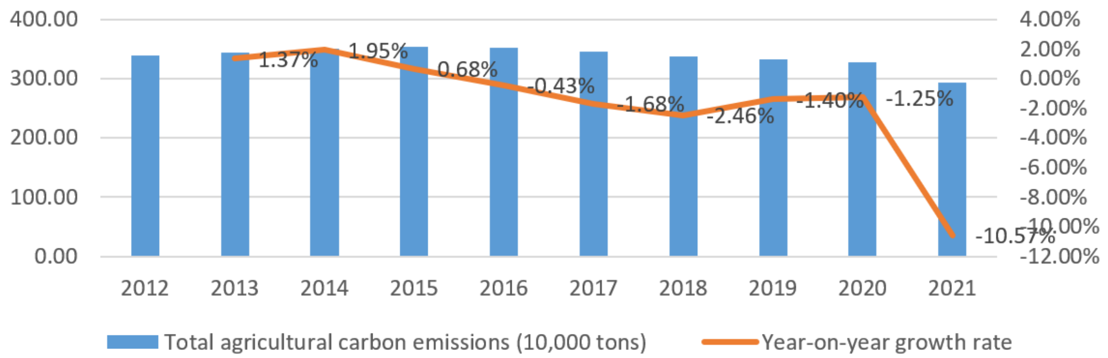

Figure 1: Total agricultural carbon emission and year-on-year growth rate in Dongting Lake Area (2012-2021)

3.2 Analysis of Agricultural Green Total Factor Productivity Results in Dongting Lake Area

Based on the super efficiency SBM model, this paper measured the agricultural green total factor productivity of Yueyang City (except Pingjiang County), Changde City (except Shimen County), Yiyang City (except Anhua County) and Dongting Lake District during 2012-2021. The results are shown in Figure 2.

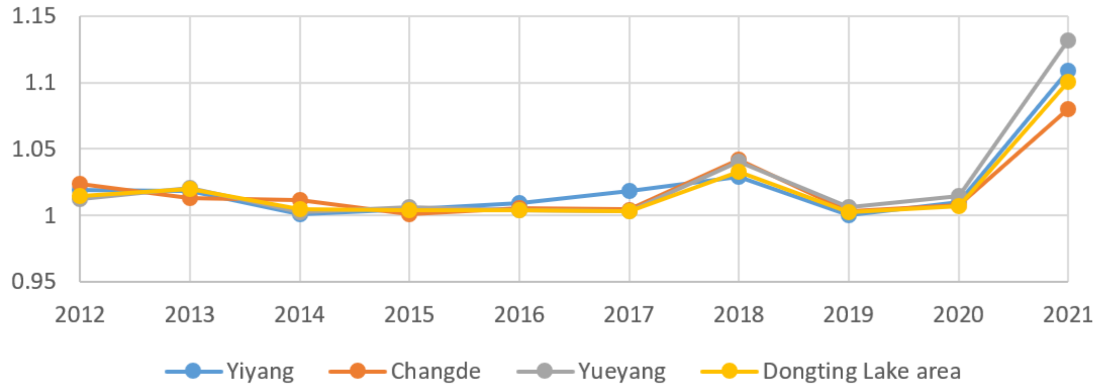

Figure 2: Change trend of agricultural green total factor productivity around Dongting Lake Region from 2012 to 2021

According to Figure 2, from 2012 to 2021, the agricultural green total factor productivity in Dongting Lake region showed a trend of flattening, declining and rising on the whole, and was all in an efficiency state with the agricultural green total factor productivity value greater than 1.

According to its change characteristics, it can be divided into three stages: the first stage is from 2012 to 2018. The agricultural green total factor production efficiency values of the three cities and the efficiency values of the Dongting Lake area showed a relatively stable trend and reached a small peak in 2018, as follows: Around Dongting Lake 1.03, Yueyang 1.04, Changde 1.04, Yiyang 1.03, this stage may be due to the implementation of the "12th Five-Year" plan, the government gradually strengthened the supervision of agricultural ecological environment protection around Dongting Lake, effectively improving the utilization rate of agricultural resources. The second stage is from 2018 to 2019. The agricultural green total factor productivity in the area around Dongting Lake is in a declining period, which may be due to the fact that the extensive economic model of fish and rice around Dongting Lake has not been completely changed, and the phenomenon of excessive exploitation of resources, such as the extinction of fish and shrimp fishing and river sand mining, has resulted in the increase of agricultural carbon emissions. The third stage is 2019-2021. The agricultural green total factor productivity of Dongting Lake region is in a period of rapid rise, which may be because the 13th Five-Year Plan has reached a critical moment, and the agricultural ecological environment governance effect of Dongting Lake region is obvious, and the green economy is vigorously developed, which keeps the agricultural green total factor production efficiency at a high level.

4. Conclusion

4.1 Research Conclusions

From the perspective of total agricultural carbon emissions, from 2012 to 2015, the total agricultural carbon emissions around Dongting Lake continued to increase from 3.395 million tons to 3.532,500 tons, an increase of 137,500 tons in just four years. However, from 2016, the total carbon emissions began to decline, until 2021, the total carbon emissions dropped to 2.937,300 tons. Its year-on-year growth rate is negative from 2016 to 2021, and the overall trend is downward. This shows that the carbon emission in the Dongting Lake area has been more and more controlled in recent years, and the road of green agricultural development has reached a new level.

In terms of the proportion of carbon emission sources, among the six types of agricultural carbon sources, the carbon emission caused by chemical fertilizer accounts for the largest proportion, more than 76 percent. However, the carbon emissions caused by agricultural film, agricultural diesel and ploughing account for a very small proportion, especially ploughing only accounts for about 0.25% of the total agricultural carbon emissions.

In terms of agricultural green total factor productivity around Dongting Lake area, the core content of this study, whether Yueyang City (except Pingjiang County), Changde City (except Shimen County), Yiyang City (except Anhua County) or the whole Dongting Lake area, has a high agricultural green total factor productivity, and their change trend is consistent, indicating that after years of adjustment and governance, Agricultural development around Dongting Lake area is moving towards a road of green and sustainable development.

4.2 Policy Recommendations

Increase financial support. The level of financial support for agriculture directly affects the level of agricultural green total factor productivity. Although a series of agricultural subsidy policies have been issued around Dongting Lake District, there may be some problems such as unreasonable structure, insufficient strength and inaccurate target of financial support for agriculture. Therefore, in order to further improve the influence of financial support for agriculture on agricultural green total factor productivity, The government departments of Changde City, Yiyang City and Yueyang City also need to give subsidies to green agricultural workers according to their respective agricultural location conditions, such as reducing the price of seeds and agricultural film, and directly encouraging farmers who buy green, ecological and environmental protection agricultural behaviors such as organic fertilizers in the form of bonuses or subsidies.

Improve the efficiency of agricultural resources utilization. First, the government can adopt agricultural policies that are favorable to farmers and attractive enough for farmers to use organic fertilizers instead of chemical fertilizers in agricultural production. Secondly, let farmers clearly understand the harm of pesticides to people and crops, introduce biopesticides to them and provide operable measures for farmers to use in production; Third, "white agricultural film" is also one of the sources of agricultural pollution, so we need to vigorously promote the new technology research film, and as soon as possible applied to agriculture; Fourth, the use of agricultural diesel can be replaced by clean energy.

Strengthen the investment of science and technology funds and improve agricultural technology. Establish a low-carbon agricultural development mechanism based on the modern agricultural industrial technology system. Now all walks of life need the support of science and technology. As the global primary industry, agriculture needs to realize the green and high-quality development of modern agriculture through scientific and technological innovation, and the green and sustainable development of agriculture depends more on the amount of scientific and technological funds and technical talents invested. The development of low-carbon agriculture around Dongting Lake requires the introduction of relevant equipment and talents to promote the application of new technologies in agriculture.

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