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Article

Chinese Agriculture towards "Green & Grain" Productivity Growth: Evidence from Jiangsu Province

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Abstract: China is striving to leverage the power of science and technology to green its agriculture while increasing grain productivity. In this context, this study presents the green growth rate of agriculture from the DEA-based Green Total Factor Productivity (GTFP) indicator, together with the growth rate of grain yields, and applies it to the case of Jiangsu, a major grain-producing province with a well-developed economy. It is found that Jiangsu's agriculture has generally performed well in the implementation of the two major national strategies of green development and grain security, especially in the northern Jiangsu, which is a major grain-producing area. In contrast, the phased fluctuations of green growth in agriculture in Southern Jiangsu are more pronounced, with even negative green growth occurring during the green agriculture movement. Much of the volatility in agricultural green growth at the provincial, subregional, municipal level comes from the effects of the movement of the green technology frontier led by best practitioners. Accordingly, the possibility of improving the weak state of the catch-up effect on green growth is explored from the perspective of the Chinese government-led agricultural science and innovation system; it also traces the green agricultural initiatives in the main grain-marketing areas that have failed to deliver the expected green growth, and recommends a review of such policies and refinement of the GTFP Index tool for assessing sustainable green growth.

Keywords: green development in agriculture; grain security; frontier movement effect; catch-up effect; Chinese government-led agricultural science and innovation system; Malmquist-Luenberger Productivity Index

1. Introduction

As a populous country with scarce per capita resources, China has spent nearly half a century in an endeavor to make the growth rate of grain out eventually exceed that of its population. Since the end of the 20th century, when the problem of hunger was completely solved, China has entered a new era with green agricultural development as its new mission. The National Green Development Initiative (NGDI) began at the turn of the century with the" Grain for Green" program by converting the sloped farmland to forest(grass) [1]. NGDI in agriculture has stepped up since the mid-2010s, as evidenced by China's Ministry of Agriculture and Rural Affairs (MARA) releasing zero growth plan of chemical uses by 2020 [2] in 2015, and subsidy programs for farmland rotation, fallow conservation and recovery of degraded land [3] in 2016. The biggest movement is then the State Council's call in 2017 to promote green agricultural development through the establishment of institutions and incentive systems [4], which was followed by the release of the Technical Guidelines for Green Agricultural Development in 2018-2030 [5]. Moving towards greener agriculture has now officially been a national strategy with the release of 14th Five-Year Plan for Green Agricultural Development (2021-2025) by MARA together with the other five ministries [6].

There appears to be a trade-off between green agriculture and grain productivity, as evidenced by the slowing cereal yields in some European regions when moving to green agriculture [7]. For China, with its large population and scarce per capita resources, greener agriculture should not come at the expense of grain productivity. In other words, ensuring the security of grain supply through sustained productivity growth, which has always been regarded as a cornerstone of political stability, takes precedence over a green agriculture strategy [8]. Under the call "Chinese people's rice bowls should be filled with Chinese-produced food", the Chinese Government has instructed party committees and governments at all levels to share responsibility for increasing food productivity within their jurisdictions [8], with policy priorities tilted towards staple grains of food and the country's major grain-producing areas. To this end, following the State Council's release of a special plan to add 100 billion jin[1] of grain production capacity in 2009, the No. 1 Document of the CPC Central Committee in 2023 proposed the implementation of a new round of actions to enhance grain production capacity by another 100 billion jin [9], and a core task is to increase the yields of staple grains, especially in the main grain-producing region. As a result, Chinese agriculture has long faced a dual mission: to enhance grain productivity as the mandatory task, and then to strive for green development. While exploring win-win possibilities and measures to achieve these dual objectives is a hot topic in academic and policy circles [4–6], there are few regional empirical studies to assess the dual performance.

With the notion that "science and technology are the primary productive forces", China has witnessed government-led agricultural scientific and technological innovation (STI) to address hunger problem in the past, for instance, thanks to breakthroughs like hybrid rice varieties and their large-scale extension among farmers; the nation still aspires to make agriculture greener by leveraging the power of STI. Given the much-criticized disconnect between technology supply and farmers' needs - the so-called dichotomy of government-led STI in practice between research and development (R&D) and its application 6 - there is a need for clear policy-guidance indicators to demonstrate the respective roles of R&D and its application of STI systems in promoting green agriculture. The most popular tool for measuring economic growth, the DEA-based Total Factor Productivity (TFP) Index, can indicate the performance change and identity its sources related to production technology: technological change (TC) and technological efficiency change (EC) [7,8], which roughly corresponds to R&D and its application components, respectively. The tool has been widely used in regional empirical studies for its policy value [17,18]. There has been much academic and policy interest in exploring China's agricultural growth in the context of market-led economic reforms through the introduction of this tool [11–13], as well as the regional heterogeneity of agricultural productivity changes [22,23]. Green development in agriculture has attracted a new wave of research interest [24,25], with much of the research focusing on how to measure green Total Factor Productivity (GTFP) [18,20] and to explore its drivers [21–23]. To date, few studies have investigated the sources of such green productivity growth from the perspective of a STI system with Chinese characteristics, which is the policy value of the tool.

This study aims to explore two major challenges facing Chinese agriculture: whether the two strategic tasks of green agriculture and grain security can be achieved in tandem; and how STI can drive agriculture greener under the mandatory task of increasing grain productivity. Given that the increasing per-hectare grain yields is the mandatory indicator for grain security in a densely populated country, this study introduces the GTFP Index and improves it into a Green Growth Rate indicator with its two completely decomposed terms, which allows for juxtaposing and comparing the dual performance dynamics of the agricultural production system in one coordinate system. In this way, we selected a major grain-producing province in the most economically developed region to monitor its agricultural progress on the dual strategies. The study found that the provincial agriculture performance well by and large, but with significant regional heterogeneity between the main grain-producing and grain-marketing zones. For much of the study period, the movement of the green technology frontier, led by best practitioners, has been the main contributor of fluctuations in green agriculture in most regions. Our study contributes to the existing literature in two ways: first, it refines the GTFP Index into a Green Growth Rate indicator and decomposes it completely into two technology-related factors. This allows the green growth system to be placed in a coordinate system with growth in grain productivity, so that the performance dynamics of the dual agricultural strategies can be visualized and compared, and the sources of green agricultural growth can be traced

[1] Jin, the Chinese unit of measurement for the weight of agricultural products, with 1 jin= 0.5 kg

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directly. Second, analytical perspectives that incorporate China's agricultural policy context, including understanding the technology-related factors that constitute green growth in the light of China's agricultural R&D and extension system, as well as exploring the regional heterogeneity in agricultural productivity growth in terms of grain producing & marketing zoning policies.

2. Methods and Materials

2.1. Study Region

Jiangsu Province is located in the northern part of the Yangtze River Delta (YRD) which is the most economically developed and populous region in China. It spans five latitudes from south to north, and its 13 municipalities are grouped into 3 subregions according to their proximity to the economic core of the YRD: Southern Jiangsu, Central Jiangsu, and Northern Jiangsu (Figure 1). The predominantly plain topography and dense population have made Jiangsu a nationally renowned region for intensive high-yield agriculture. With the advancement of the modernization, Jiangsu's agriculture has experienced a shift in the production mode in which capital (including chemical fertilizer inputs) replaces labor, and there was once an unsustainable trend of intensive high-yield [32], exemplified by the fact that the intensity of fertilizer use in Jiangsu was once much higher than the national average [2,33].

As the only remaining grain-producing province in the developed southeastern coastal China, Jiangsu not only contributes financial resources, but also grains to the nation. Higher grain yields have always been the top priority for Jiangsu's agriculture, since there is no more room for expansion of grain area for such an economically developed region with limited arable land, where grain production itself does not have the advantage of comparative economic returns. In terms of the grain self-sufficiency balance between production and consumption, Jiangsu's status as a major grain-producing province relies mainly on the relatively arable land-rich central and northern Jiangsu, while southern Jiangsu has become the main grain marketing area. With sufficient financial resources and advanced technological advantages, Jiangsu seeks to become a model for simultaneously achieving greener agriculture and higher grain yields. As such, Jiangsu is a good empirical region to demonstrate how to achieve a green transition through technological innovation under the mandate of increasing grain productivity.

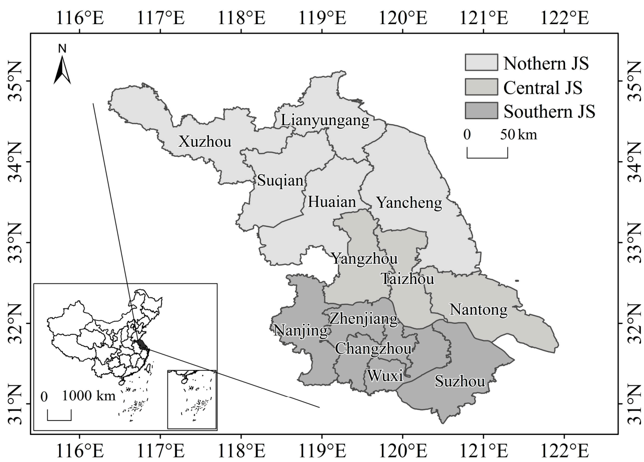

Figure 1. Location and zoning of Jiangsu (JS) Province.

2.2. Calculation of Green Growth Rate in Agriculture and Its Decomposition Terms

Green growth in agriculture is a process of increasing green productivity by actively incorporating innovative elements such as cutting-edge green technologies that can minimize resource consumption and environmental damage while maximizing agricultural outputs. The most commonly used tool for calculating this productivity is the Total Factor Productivity (TFP) method based on Data Envelopment Analysis (DEA) with the distance function [14]. The DEA-Malmquist

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Productivity Index (MI), is designed to measure the productivity growth over time, as well as its two production-technology related terms, namely, technical change (TC) and technical efficiency change (EC). Changing TFP (TFPC) is the product of TC and EC, as shown in its well-known formula, $TFPC = TC \times EC$ [15].

The Malmquist-Luenberger Productivity index (MLI), upgraded from MI, incorporates environmental undesired outputs into the Directional Distance Function (DDF) [34], which makes it possible to monitor the dynamics of green TFP (GTFP). DDF represents a green production technology that maximizes desired output while reducing undesired output. The DEA-MLI can also be derived from its two components, just as the MI system to indicate TFPC. The MLI measures GTFP change between the previous year *t*-1 and the current year *t* ($GTFP_t/GTFP_{t-1}$), but this study needs to measure it as rate-of-change form like $\left(\frac{\Delta GTFP}{GTFP_{t-1}}\right) \times 100\%$, to denote the dynamics of Agricultural Green Growth (AGG) in %.

When converting the TFPC to its rate-of-change form, the multiplication relationship between its two decomposition terms TC and EC [15], can be converted into a summation relationship between the rate-of-change forms of the two terms. Our derivation still begins with that famous multiplication formula:

$$TFPC = \frac{TFP_t}{TFP_{t-1}} = \frac{TC_t}{TC_{t-1}} \times \frac{EC_t}{EC_{t-1}} = TC \times EC \tag{1}$$

One component of TFP is TC (TC_t/TC_{t-1}), representing the green technological frontier transfer from the year *t*-1 to the year *t*. Its value greater than 1 indicates an innovation between the two periods, i.e., green technological progress (innovation) led by best practitioners, implying advances in agricultural R&D, realization of cutting-edge technologies in demonstration sites. The other component, EC (EC_t/EC_{t-1}), reflects proximity to the green production frontier; its value greater than 1 indicates that the production unit is catching up compared to the previous year (catch-up) [15], which is associated with the diffusion of green technologies, i.e. cutting-edge technologies are applied by production laggards.

$$AGG = \frac{\Delta TFP}{TFP_{t-1}} = \frac{(TFP_t - TFP_{t-1})}{TFP_{t-1}} = TFPC - 1 \tag{2}$$

That is:

$$TFPC = \frac{\Delta TFP}{TFP_{t-1}} + 1 \tag{3}$$

likewise,

$$TC = \frac{TC_t}{TC_{t-1}} = \frac{\Delta TC}{TC_{t-1}} + 1 \tag{4}$$

$$EC = \frac{EC_t}{EC_{t-1}} = \frac{\Delta EC}{EC_{t-1}} + 1 \tag{5}$$

Substituting Equation (3)(4)(5) into Equation (1) yields the following equation:

$$AGG = TC_{effect} + EC_{effect} = \frac{\Delta TFP}{TFP_{t-1}} = \frac{\Delta TC}{TC_{t-1}} + \frac{\Delta EC}{EC_{t-1}} + \frac{\Delta TC}{TC_{t-1}} \times \frac{\Delta EC}{EC_{t-1}} \tag{6}$$

Thus, AGG consists of the rate-of-change form of TC and EC, which are the two decomposition terms of TFPC. The last term on the right-hand side in Equation (6) is co-created by TC and EC, whose contributions to AGG are calculated as follows according to the "co-creation and equal sharing" rule [35]:

$$TC_{effect} = \frac{\Delta TC}{TC_{t-1}} + \frac{1}{2}\left(\frac{\Delta TC}{TC_{t-1}} \times \frac{\Delta EC}{EC_{t-1}}\right) \tag{7}$$

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$$EC_{effect} = \frac{\Delta EC}{EC_{t-1}} + \frac{1}{2}\left(\frac{\Delta TC}{TC_{t-1}} \times \frac{\Delta EC}{EC_{t-1}}\right) \tag{8}$$

AGG is therefore completely decomposed into two factors related to STI: Frontier movement effect (TC_{effect}) and Catch-up effect (EC_{effect}). The performance dynamics of agricultural production system is then interpretated by agricultural green growth rate (AGG, in %) and its two contributing factors (TC_{effect} & EC_{effect}, also in %), along with the growth rate of grain yields (GYG, in %) as a proxy variable for changes in grain productivity.

2.3. Design of Indicator Sets for Green Growth in Agriculture

AGG is originally calculated from MLI as a proxy variable for GTFPC, measured for agricultural production systems with well-defined input-output relationships. In this study, the boundary of the agricultural production system is defined as the arable cropping system with 8 inputs:(1) sown area of crops (10^3hm^2); (2) effective irrigated area (10^3hm^2); (3) labor force (10^3 persons); (4) mechanical power (10^3 kwh); (5) Chemical fertilizer (t); (6) Chemical pesticide (t); (7) agricultural film (t), (8) diesel fuel (t).

Given that low-carbon agriculture is a key strategy for green growth [36], the three outputs include (1) agricultural output value (10^6 yuan), as well as the two carbon-related indicators: (2) carbon sink (10^4t); and (3) carbon emissions (undesired) (10^4t). Agricultural carbon sinks are measured by the biomass production of regional crops and their corresponding carbon sequestration coefficients [37]. Major crops in the agricultural statistics include: wheat, rice, maize, soya beans, potatoes, peanuts, canola, cotton, hemp, vegetables and melons. Carbon emissions in this study include the major carbon cost items (fertilizers, pesticides, plastic film and diesel fuel in tonnes, and electricity in kwh), as well as rice cultivation, irrigation and ploughing land, with the total amount of emissions still measured by the respective inputs and their corresponding emission factors [38,39].

2.4. Data Sources and Preprocessing

This study takes 13 municipalities of Jiangsu Province as the evaluation unit, and 2000-2020 are sample years for observations. The data of relevant indicators used for the calculation of grain yields and GTFP, including agricultural carbon sinks, carbon emissions, are all taken from the Rural Statistical Yearbook of Jiangsu Province in the corresponding years. Among them, the annual output value data is deflated according to the price index of relevant items based on the base year of 2000 for comparability.

Multi-year average AGG (in %) across regions and time periods is calculated from the GTFPC in Equation (2), which is taken from the geometric mean of the MLI measurements for the relevant region and relevant year. In addition, MaxDEA 7.0 software was used in the linear programming solution [40] and an output-oriented global MLI was chosen for its free from linear programming infeasibility that plagues the sequential MLI [41,42].

Multi-year average GYG (in %) is calculated with the power function in excel software, according to the general algorithm for compound annual growth rate. To eliminate fluctuations in grain yields due to climatic and other factors, the values of grain yields for the base and end years were pre-processed as three-year averages. Missing values in the statistical yearbook are supplemented with data using trend extrapolation.

3. Result and Analysis

3.1. Overview of Trends in Agricultural Inputs and Outputs

As a grain security mandatory indicator, per-hectare grain yield is to some extent recognized as the desired output of agricultural production. From 2000 to 2020, grain yields in Jiangsu showed a stable and then increasing trend, hovering at a high level after 2015 (Figure 2). Southern Jiangsu has the highest level of grain yields but the lowest increase in yields with a 20-year average growth rate of 0.34%; northern Jiangsu has the lowest average yields but the highest average growth rate of 0.70%.

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For the three output indicators of agricultural system, significant increase in the economic output of the province's the plantation sector has recently stalled; increases appear to be higher in the north than in the south; Agricultural carbon sinks, as another desired output, have experienced a fluctuating upward and then relatively stable process, and the increase in northern Jiangsu still seems to be more evident; Agricultural carbon emissions, as only undesired output item in this study, first fluctuated and then stabilized, with an overall decline of 4.23% over the whole period, with a more pronounced decrease in the southern Jiangsu (Figure 2).

In terms of agricultural inputs, the province's crop sown area and effective irrigated area, which represent inputs of arable land and water resources, were relatively stable during the study period, with a clear trend of expansion in the north and shrinkage in the south. The most notable change in agriculture during this period is the increasing machinery power accompanied by decreasing labor force. Regarding agrochemical usage, diesel fuel and agricultural film has generally increased and remained relatively stable since the mid-2010, while fertilizer has continued to decline steadily from a high level, and pesticide declined overall, peaking in 2005 and continuing to decline (Figure 3).

In short, since the beginning of the 21st century, Jiangsu's agriculture has undergone at least two major changes while fulfilling the national grain security mandate: one is the advancement of large-scale production, manifested in a stable sown area, increasing mechanical power but decreasing manpower, implying an era of "machine for labor "; the other is the green tendency, which is shown by the decline in agricultural chemical inputs from a high level while maintaining higher economic output.

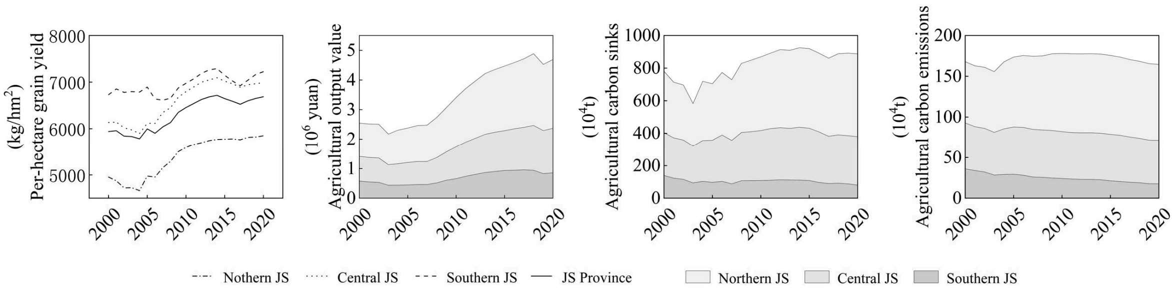

Figure 2. Trends in agricultural outputs in Jiangsu, 2000-2020.

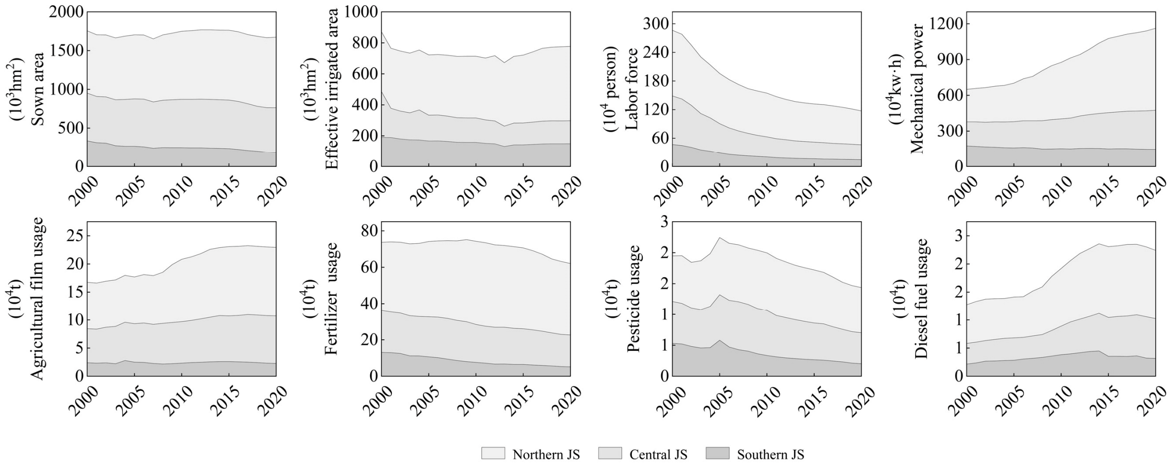

Figure 3. Trends in agricultural inputs in Jiangsu, 2000-2020.

3.2. Phasing of provincial agriculture towards "green with grain" growth

Annual rates of AGG and GYG in Jiangsu showed common ups and downs in most years. Based on the magnitude and direction of AGG and GYG fluctuations (Figure 4), the entire sample years can be divided into following three phases, corresponding to different periods of agricultural policy:

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Phase Ⅰ (2000-08) under China's transition from market-led to policy-supported agriculture. With China's accession to the World Trade Organization (WTO) in 2001, a strategic restructuring of agriculture oriented towards market competitiveness was initiated at the turn of the century. This was followed by successive slumps in grain production from 2000 to 2003 [43], resulting in a lack of self-sufficiency in grain. China then implemented a series of policies to support agriculture from 2004 onwards, and thus entering a new era of subsidizing farmers rather than taxing them as it had done in the past 2000 years. In this context, agricultural productivity in Jiangsu has been subject to large fluctuations and frequent anomalies, most notably in the period prior to the introduction of agricultural support policies, such as AGG backward while GYG forward (2000-01), and double declines in AGG and GYG (2001-02, 2002-03). Taking the 2004 policy intervention as the cut-off point, GYG and AGG moved from a rare streak of downward or negative growth to both oscillating upward. During this stage, the annual rate of AGG turns from negative to positive, mainly due to the backward and upward movement effect of the green technology frontier in TC.

Phase Ⅱ (2008-15) of China's sustained agricultural support policies. The surge in international grain prices in 2007-08 triggered concerns about a nationwide grain crisis [44], and coupled with the 2008 international financial tsunami, China further consolidated its agricultural support and protection system, and speeded up productivity-enhancing investments as well as producer subsidy programs. Jiangsu Province has strong financial and S&T resources to support agriculture, and AGG and GYG have shown successive years of growth, although the rate moving green has gradually slowed down in the later years. AGG in this stage mainly came from the advancing effect of the green technological frontier, and the effect of catching up with the technological frontier tended to stagnate, which in some years manifested itself as a constraint on green growth.

Phase III (2015-20) under China's supply-side structural reform of agriculture. Market interventions to raise farmers' incomes and yields result in serious "structural problem" in supply and demand. Supply-side structural reform under the strategy of "Store Grains in Technology" and " Store Grains in Land", has been initiated since 2015. Agricultural environmental programs such as zero-growth in the usage of fertilizers and pesticides are widely promoted across the region, and Southern Jiangsu has taken the lead in promoting the cropping system reform in the rice-wheat rotation area, shifting to rice-green rotation [45]. This phase also saw turbulence in AGG and GYG, such as a double dip in 2015-16, while GYG rose and AGG fell back in 2016-17 and 2018-19. The province's AGG has not maintained a sustained upward trend, mainly due to upward and downward fluctuations in TC and EC.

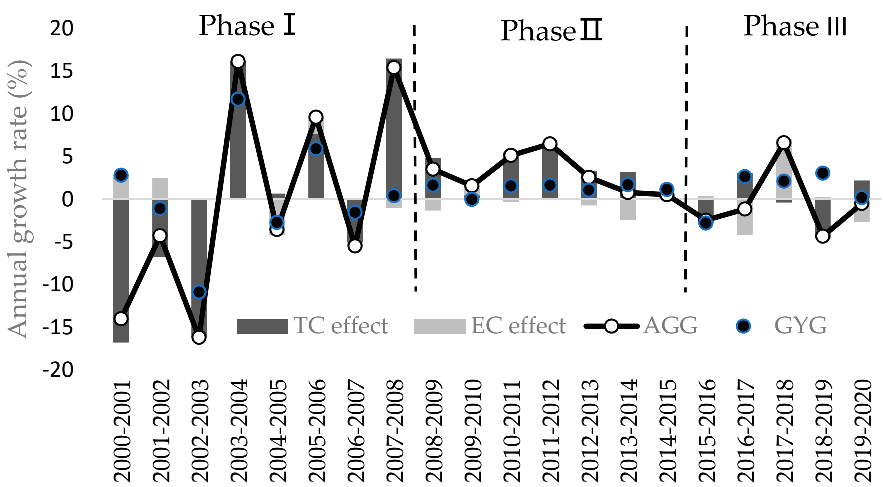

Figure 4. Evolutionary stages based on annual fluctuations in agricultural growth in Jiangsu, 2000-2020.

3.3. Regional heterogeneity in Agricultural Growth for "Green with Grain"

In terms of the annual rate of change, the AGG in Jiangsu is significantly more volatile than that of the GYG (Figure 4), but in terms of the multi-year average rate during 2000-20, the AGG is relatively stable (0.49%) and lower than the GYG (0.63%), as shown in Table 1. AGG during the whole period is mainly driven by technological progress (0.53%), and the effect from technical efficiency (-0.04%) is weak. The average rate of AGG during 2000-2020 in Northern Jiangsu is still higher than that of Southern Jiangsu. AGG in northern Jiangsu is mainly supported by both TC and EC, while that in southern Jiangsu is mainly contributed by TC. Central Jiangsu has the weakest AGG, mainly because the forward effect of TC is attenuated by the backward effect of EC.

From the phase-by-phase change, GYG in northern Jiangsu has maintained a continuous upward trend, with the strongest growth in phase II. Over the same period, AGG has shifted from a regression in phase I to a rebound in phase II, which determined by the TC effect from regression to progress, and accelerated again in phase III, thanks largely to the improvement of EC. It can be seen that the northern Jiangsu, as the largest grain-producing area, also has the most outstanding performance of green growth in subregional agriculture.

The phase changes of AGG and GYG in central Jiangsu, which is also a major grain producing area, are roughly similar to those in northern Jiangsu, except that the magnitude of change is not as large as that in northern Jiangsu. The negative average growth of AGG in phase I came mainly from a relative decline in EC, while growth in phase II was driven by TC, with EC still lagging relatively behind; and sustained growth in phase III was driven by a combined contribution of TC and EC.

Southern Jiangsu, as the main grain marketing area incapable of grain self-sufficiency, has very different characteristics of agricultural growth. In the first stage of the structural-strategic adjustment period, the decline in GYG in the region was accompanied by a decline in AGG caused by a negative effect from TC, implying the region's abandonment of agricultural growth at that time; however, in phase II, both AGG and GYG bottom out and reverse into a rising trend, especially the high-speed rise in AGG brought about by the rapid advancement of the green technological frontiers. In phase III, although GYG is still rising at an accelerated rate, AGG reverses to a downward trend, which mainly stems from the regression of both TC and EC.

Table 1. Comparison of Jiangsu's agricultural growth rate (in %) by phase and by region.

Region	Growth rate	Whole period	Phase I	Phase II	Phase III
Southern Jiangsu	GYG	0.34	-0.19	1.02	0.23
	AGG	0.55	-1.86	6.11	-3.05
	TC_{effect}	0.70	-2.31	6.11	-1.73
	EC_{effect}	-0.15	0.45	0.00	-1.32
Central Jiangsu	GYG	0.50	0.18	1.14	0.14
	AGG	0.01	-0.61	0.47	0.38
	TC_{effect}	0.37	0.06	0.88	0.16
	EC_{effect}	-0.36	-0.67	-0.42	0.22
Northern Jiangsu	GYG	0.70	0.52	1.30	0.14
	AGG	0.71	-0.36	1.23	1.71
	TC_{effect}	0.45	-0.85	2.10	0.24
	EC_{effect}	0.26	0.49	-0.87	1.47
whole Jiangsu	GYG	0.63	0.44	1.16	0.18
	AGG	0.49	-1.00	2.90	-0.45
	TC_{effect}	0.53	-1.21	3.34	-0.55
	EC_{effect}	-0.04	0.21	-0.44	0.10

3.4. Performance Changes in Municipal Agriculture for "Green with Grain" Growth

In terms of the average growth rate during 2000-20, all 13 municipalities have stable or rising GYG, implying well performance in grain security mandate. Agriculture in 11 municipalities achieved green growth through the contribution of TC (Figure 5), suggesting they are on a synergistic track of grain and green co-growth.

Although the average AGG for the entire period in the Southern Jiangsu region is relatively low (Table.1), the municipalities in Southern Jiangsu, except Changzhou, have an average AGG of more than 2%. Changzhou's apparent falling AGG stems from its significant decline in EC, which implies that the technology laggards are not endeavoring to catch up with the green technological frontiers, despite the fact that the green technology frontiers are still developing at a rapid pace. The AGG in northern Jiangsu shows an overall upward trend, with Xuzhou and Suqian showing higher rates, the former mainly due to the contribution of TC, and the latter due to the joint promotion of TC and EC. The AGG of all 3 municipalities in Central Jiangsu is mediocre, with Yangzhou's AGG stagnating due to the stagnation of both TC and EC.

From the recent phase (2015-20), GYG mostly slowed down and even a few showed a small decline, while AGG showed a clear north-south divergence. Northern Jiangsu is in a better situation for agricultural growth, with GYG and AGG generally rising, and agriculture at the municipal level except Yancheng is on an accelerated green growth trajectory. Yancheng's weaker AGG mainly stems from the retreat of the greening technology frontier, but the catch-up effect remains strong. Suqian's AGG is mainly supported by the catching-up effect, while the other 3 municipalities owe it to the frontier movement effect, relative to the baseline of advanced technology in the region as a whole (Figure 5). Southern Jiangsu in the phase seems to be the most severe, with AGG in a state of general stagnation or even regression. Among them, Nanjing's GYG and AGG are in full stagnation; Suzhou, Wuxi and Zhenjiang's AGG is also declining due to the regression of the technological frontier; Changzhou's regression is the largest, with AGG and its TC and EC components, in full decline along with the decline of GYG. Central Jiangsu has a tendency to follow in the footsteps of Southern Jiangsu, with Yangzhou and Taizhou stagnating in AGG including its two components while GYG rises; Nantong's GYG declines while AGG tends to rise, which stems mainly from the combined advancement of EC and TC.

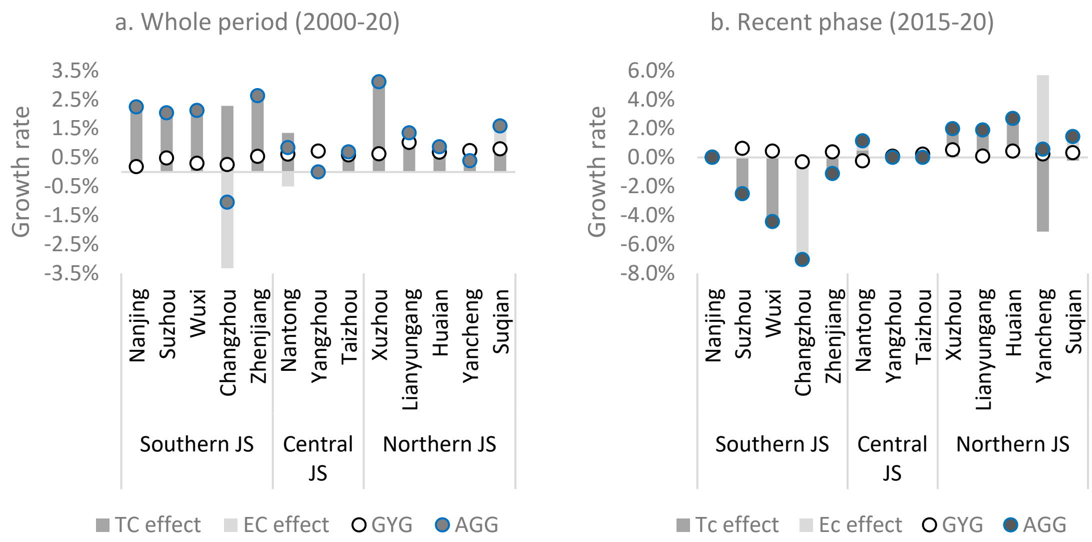

Figure 5. Average growth rate of municipal agriculture during: a 2000-2020; b 2015-2020.

4. Discussion

4.1. Green Growth Sources from Frontier Movement Effects or Catch-up effects ?

This study identifies the sources of green growth in Jiangsu's agriculture at the provincial, sub-regional and municipal levels, and finds that the growth is largely contributed by the technology frontier movement effect, i.e., it is mainly due to advances in the green technology frontier led by the

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pioneer practitioner, while the laggards' lack of enthusiasm in catching up with the frontiers is a bottleneck factor for growth. This result is broadly consistent with regional empirical studies measuring TFP growth in Chinese agriculture at the provincial level [22,26,30]. China's government-led agricultural STI system, through public agricultural r R&D and extension networks, has achieved world-renowned successes in increasing grain productivity, such as the breeding of super rice varieties and their large-scale dissemination among farmers. The strength of this top-down STI system lies in the rapid advancement of the frontiers of technologies adopted in R&D test beds and demonstration areas, while the limitation may lie in the weak catch-up effect, i.e. the lag in the adoption of cutting-edge technologies by farmers due to possible mismatches between the supply of the technology and the farmers' or market demands

To break through such self-contained and unconnected state between innovation and diffusion, Chinese governments at all levels have encouraged S&T personnel to go to the grassroots and the fields, and have sought to promote technology diffusion through policies such as expert dispatchers and Science and technology backyard [13]. These policy fixes are still confined to the production aspect of agriculture. In fact, the government-led STI system is indeed applicable to the stage where agriculture pursues high grain yields to meet the basic needs of a large population. Green agriculture, which aims to produce green agricultural products supported by green technologies, faces more dynamic and diversified markets than the task of enhanced grain productivity. However, under this top-down STI system, there is still an obvious catch-up effect (Figure 5) in a few districts in northern Jiangsu, pending in-depth field case studies.

4.2. Green Growth Supported by Major Grain-producing Regions or Major Grain-selling Regions?

Our study found that the northern Jiangsu as a whole performed the best, achieving a high AGG while maintaining GYG steadily, with green growth mainly coming from the frontier movement effect (Table 1, Figure 5). This implies that the main grain-producing regions were capable of balancing the objectives of “green and grain” growth in agriculture. This achievement may still be attributed to the government-led STI system, as the Northern Jiangsu, with its relatively abundant arable land and labor resources, is a priority region for financial and S&T support to agriculture.

Southern Jiangsu, however, the fluctuations in agricultural green and grain productivity were relatively large (Table 1), though it has long prided itself on high-quality intensive agriculture. With its proximity to the agricultural market in the metropolis and its strong financial resources, Southern Jiangsu should have been a market-oriented pilot area for green agricultural technology innovation. Driven by the frontier movement effect, most municipalities did rank among the top green growth rates in the province throughout the study period (Figure 5a). Inexplicably, in the last stage, AGG has generally declined due to a large drop in the frontier movement effect (Figure 5b). Under the advocacy of supply-side reforms to "Storing Grains in Land", southern Jiangsu has taken the lead in implementing the fallow rotation project, i.e., changing the rice-green cropping system in its rice-wheat double-cropping area [45]. This may lead to a reduction in the economic output of the cropping system and in carbon sinks associated with biomass production. The result is likely to be a retreat from the green technology frontier, as the output-oriented models applied in this study measure the ability to achieve as much economic output and carbon sinks as possible with as little undesired output of carbon emissions as possible.

That anomalous growth in agricultural greening in Southern Jiangsu during the supply-side reform deserves further scrutiny in terms of both policy and greening measurements. One is a review of certain green agricultural policy practices: is it appropriate to implement arable land fallow (including seasonal fallow) on a large scale in areas like Southern Jiangsu, which possesses high-quality arable land resources? This promotion of a green transition in production patterns at the expense of some loss of current agricultural output and carbon sinks is, in this case, identified as counterproductive and contrary to green growth. The other is two reflections on green measurement methods in agriculture. First, the design of output/input indictor sets. In this case, the shift in cropping systems from "rice-wheat" to "rice-green" may generate positive externalities, such as agroecological and cultural services, that go beyond the system boundaries of the cropping system assessment. Second, in terms of GTFP tool, it measures the relative efficiency of the current year's combined inputs in achieving the current year's combined outputs. However, in this case, the cropping structure was adjusted from "rice-wheat" to "rice-green" in order to gradually restore land fertility over the years. In response to the lagging performance of green policies, the current agricultural GTFP measurement tool needs to be improved to be competent in the assessment of sustainable green development.

5. Conclusions

This study uses productivity growth indicators to evaluates the performance of Chinese agriculture in implementing a green development strategy under grain security as a mandatory goal. Along with the growth rate of grain yields, which is the core performance indicator of the grain security mandates, an improved green growth rate indicator based on the DEA-ML index is introduced to identify sources of green growth in agriculture. Jiangsu, a major grain-producing province in China's economically developed region, was selected as the observation region. It is found that provincial agriculture has largely achieved the grain- green co-growth during the period 2000-2020. However, there is differentiation within the province, for the northern Jiangsu as major grain-producing zone, the average rate of agricultural green and grain growth is relatively high, and changes are relatively stable with the phased adjustment of agricultural policies; while for the southern Jiangsu as the main grain marketing zone, there have been phased fluctuations in the grain and green growth rate, and even a generally negative green growth rate during agricultural green movement. The advancement of the green technology frontier led by the best practitioners mainly contributes to agricultural green growth at various spatial levels.

Based on these findings, it is recommended that policies focus on catch-up effect, which require innovating the government-led agricultural extension system and building a market-oriented transformation of the agricultural STI system to enhance the diffusion of cutting-edge green technologies to the laggards. In response to the failure of certain agricultural green campaigns in Southern Jiangsu to bring about green growth, it is suggested that policies such as arable land fallow restoration, which may reduce production capacity, should be used with caution in high-quality agricultural zones, but it is also proposed that green growth measurement tools such as GTFP, still need to be improved.

The limitation of this study is that green productivity growth in agriculture is only traced from the two main decompositions (TC and EC) of the GTFP index, e.g. EC can be further decomposed into pure technical efficiency and scale efficiency, but due to thematic constraints, these two decompositions are not analyzed in depth in this study. In addition, we only explored the internal factors related to production technology that cause fluctuations in the green growth rate of agriculture, while the external policy context that leads to fluctuations has only been explored at the discursive level and have not been validated using modelling. Finally, only one single-factor productivity indicator, per-hectare grain yield, was selected for grain productivity, and the coupling between the two major productivity growth systems, "grain and green", was not quantitatively analyzed. These are directions for further research.

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References

1. Xu, Z.; Xu, J.; Deng, X.; Huang, Uchida, E.; Rozelle, S. Grain for green versus grain: Conflict between food security and conservation set-aside in China. *World Development* **2006**,34(1), 130–148. https://doi.org/10.1016/j.worlddev.2005.08.002.
2. Hu, L. X.; Zhang, X. H.; Zhou, Y. H. Farm size and fertilizer sustainable use: An empirical study in Jiangsu, China. *Journal of Integrative Agriculture* **2019**, 18(12), 2898–2909. https://doi.org/10.1016/S2095-3119(19)62732-2.
3. Zhao, Q. G.; Teng, Y.; Huang, G.Q. Consideration about exploring pilot program of farmland rotation and fallow system in China. *Ecology and Environmental Sciences* **2017**, 26(1), 1–5. https://doi.org/10.16258/j.cnki.1674-5906.2017.01.001. (In Chinese) .
4. General Office of the Central Committee of the Communist Party of China and General Office of the State Council. Issuance of Opinions on Innovative Institutional Mechanisms to Promote Green Agricultural Development. Available online: http://www.moa.gov.cn/gk/zcjd/201904/t20190418_6181006.htm (In Chinese).
5. Ministry of Agriculture and Rural Affairs of the People's Republic China, Gazette of Technical Guidelines for the Greening of Agriculture (2018-2030). Available online: http://www.moa.gov.cn/nybgb/2018/201807/201809/t20180912_6157155.htm (In Chinese) .
6. Ministry of Agriculture and Rural Affairs with Five Other Ministries the People's Republic China. Issuance of the National Agricultural Green Development Plan for the 14th Five-Year Plan. Available online: http://www.moa.gov.cn/xw/tpxw/202109/t20210908_6376011.htm (In Chinese) .
7. Finger, R. Evidence of slowing yield growth – The example of Swiss cereal yields. *Food Policy* **2010**, 35(2), 175–182, doi:R. 10.1016/j.foodpol.2009.11.004.
8. Qi, X. X.; Wang, R. Y.; Li, J.C.; Zhang, T.; Liu, L.; He, Y. Ensuring food security with lower environmental costs under intensive agricultural land use patterns: A case study from China. *Journal of Environmental Management* **2018**, 213, 329–340. https://doi.org/10.1016/j.jenvman.2018.02.048.
9. State Council. Opinions of the Central Committee of the Communist Party of China and the State Council on Promoting Rural Revitalization in 2023. Available online: http://cpc.people.com.cn/n1/2023/0220/c450216-32627443.html. (In Chinese) .
10. Bai, H.Z.; Tao, F. L. Sustainable intensification options to improve yield potential and eco-efficiency for rice-wheat rotation system in China. *Field Crops Research* **2017**, 211. https://doi.org/10.1016/j.fcr.2017.06.010.
11. Shen, J.; Cui, Z.L.; Miao, Y. X.; Mi, G. H.; Zhang, H.Y.; Fan, M. S.; Zhang, C. C.; Jiang, R. F.… Zhang, F. S. Transforming agriculture in China: From solely high yield to both high yield and high resource use efficiency. *Global Food Security* **2013**,2(1), 1–8. https://doi.org/10.1016/j.gfs.2012.12.004.
12. Deng, Y.; Zeng, F. Sustainable Path of Food Security in China under the background of green agricultural development. *Sustainability* **2023**, 15(3), 2538. https://doi.org/10.3390/SU15032538.
13. Jiao, X. Q.; Zhang, H. Y.; Ma, W. Q.; Wang, C.; Li, X. L.; Zhang, F. S. Science and technology backyards: a novel approach to empower smallholder farmers for sustainable intensification of agriculture in China. *Journal of Integrative Agriculture* **2019**, 18(8), 2–11. https://doi.org/10.1016/S2095-3119(19)62592-X.
14. Caves, D.W.; Christensen, L.R.; Diewert, W.E. The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica* **1982**, 50 (6), 1393–1414.
15. Färe, R.; Grosskopf, S.; Norris, M.; Zhang, Z. Productivity growth, technical progress and efficiency change in industrialized countries. *American Economic Review* **1994**, 84, 66–83. https://doi.org/10.2307/2117971.
16. Beltrán-Esteve, M.; Picazo-Tadeo, A. J. Assessing environmental performance in the European Union: Eco-innovation versus catching-up. *Energy Policy* **2017**, 240–252. https://doi.org/10.1016/j.enpol.2017.01.054.
17. Gerdessen, J. C.; Pascucci, S. Data Envelopment Analysis of sustainability indicators of European agricultural systems at regional level. *Agricultural Systems* **2013**,118, 78-90. https://doi.org/10.1016/j.agsy.2013.03.004.
18. Huang, H. Y.; Mo, R. B.; Chen, X.Q. New patterns in China's regional green development: An interval Malmquist–Luenberger productivity analysis. *Structural Change and Economic Dynamics* **2021**, 58,161–173. https://doi.org/10.1016/j.strueco.2021.05.011.
19. McMillan, J.; Whalley, J.; Zhu, L: The Impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy* **1989**, 97(4), 781–807. https://doi.org/10.2307/1832191.
20. Mao, W. N.; Koo, W. W. Productivity growth, technological progress, and efficiency change in Chinese agriculture after rural economic reforms: A DEA approach. *China Economic Review* **1997**, 2, 157–174. https://doi.org/10.1016/S1043-951X(97)90004-3.
21. Wen, G. J. Total factor productivity change in China's farming sector. *Economic Development and Cultural Change* **1993**, (10), 1–41. https://doi.org/10.2307/1154611.
22. Chen, P. C.; Yu, M. M.; Chang, C. C.; Hsu, S. H. Total factor productivity growth in China's agricultural sector. *China Economic Review* **2008**, 19(4), 580–593. https://doi.org/10.1016/j.chieco.2008.07.001.
23. Lambert, D. K.; Parker, E. Productivity in Chinese provincial agriculture. *Journal of Agricultural Economics*, **2010**, 49(3),378-392. https://doi.org/10.1111/j.1477-9552.1998.tb01279.x.

24. Xu, B.; Chen, W.T.; Zhang, G. J.; Wang, J. H.; Ping, L. Q.; Chen, J. B. How to achieve green growth in China's agricultural sector. *Journal of Cleaner Production* **2020**, 271, 122770. https://doi.org/10.1016/j.jclepro.2020.122770.
25. Chen, Z.; Sarkar, A.; Rahman, A.; Li, X.J.; Xia, X. L. Exploring the drivers of green agricultural development (GAD) in China: A spatial association network structure approaches, *Land Use Policy* **2022**, 112, 105827.
26. Laurenceson, J.; O'Donnell, C. New estimates and a decomposition of provincial productivity change in China. *China Economic Review* **2014**, 30, 86–97. https://doi.org/10.1016/j.chieco.2014.05.016.
27. Chen, Y.F.; Miao, J. F.; Zhu, Z. T. Measuring green total factor productivity of China's agricultural sector: A three-stage SBM-DEA model with non-point source pollution and CO_2 emissions. *Journal of Cleaner Production* **2021**, 318,128543. https://doi.org/10.1016/j.jclepro.2021.128543 202.
28. Liu, S.; Lei, P. F.; Li, X.; Li, Y. F. A nonseparable undesirable output modified three-stage data envelopment analysis application for evaluation of agricultural green total factor productivity in China. *The Science of the total environment* **2022**, 838, 155947. https://doi.org/10.1016/j.scitotenv.2022.155947.
29. Liu, Y.; Feng, C. What drives the fluctuations of "green" productivity in China's agricultural sector? A weighted Russell directional distance approach. *Resources Conservation & Recycling* **2019**, 147, 201–213. https://doi.org/10.1016/j.resconrec.2019.04.013.
30. Wang, Z.; Zhu, J.; Liu, X.; Ge, D.; Liu, B. Research on spatial-temporal characteristics and affecting factors of agricultural green total factor productivity in Jiangxi Province. *Sustainability* **2023**, 15(11), 9073. https://doi.org/10.3390/SU15119073.
31. Hu, S.; Lu, S.; Zhou, H. Public investment, environmental regulation, and the sustainable development of agriculture in China based on the decomposition of green total factor productivity. *Sustainability* **2023**, 15(2), 1123. https://doi.org/10.3390/SU15021123.
32. Li, Z.J.; Sarwar, S.; Jin, T. Spatiotemporal evolution and improvement potential of agricultural eco-efficiency in Jiangsu Province. *Frontiers in Energy Research*. **2021**, 9, 746405. https://doi.org/10.3389/fenrg.2021.746405.
33. Liu, Q. P.; Giesy, J. P.; Li, Z. H. Spatio-temporal distributions and environmental safety threshold of cropland Fertilization of Jiangsu Province, China. *Advanced Materials Research* **2014**, 962-965, 2110–2115. https://doi.org/10.4028/www.scientific.net/AMR.962-965.2110.
34. Chung, Y. H.; Färe, R.; Grosskopf, S. Productivity and undesirable outputs: A directional distance function approach. *Journal of Environmental Management* **1997**, 51(3), 229–240. https://doi.org/10.1006/jema.1997.0146.
35. Sun, J. W. Changes in energy consumption and energy intensity: A complete decomposition model. *Energy Economics* **1998**, 20, 85–100. https://doi.org/10.1016/S0140-9883(97)00012-1.
36. Norse, D. Low carbon agriculture: Objectives and policy pathways. *Environmental Development* **2012**, 1(1), 25-39. https://doi.org/10.1016/j.envdev.2011.12.004.
37. Weng, L. Y.; Zhu, Z. Y.; Han, X. G.; Tan, J. G. Spatial-temporal pattern of net carbon sink of farmland vegetation in Jiangsu Province. *Transactions of the Chinese Society of Agricultural Engineering*, **2018**, 34(06), 233-241. https://doi.org/10.11975/j.issn.1002-6819.2018.06.030 (In Chinese).
38. Hillier, J.; Hawes, C.; Squire, G.; Hilton, A.; Wale, S.; Smith, P. The carbon footprints of food crop production. *Journal of Agricultural Sustainability* **2009**, 7, 107–118. https://doi.org/10.3763/ijas.2009.0419.
39. Cheng, K.; Pan, G.X.; Smith, P.; Luo, T.; Li, L. Q.; Zheng, J. W.; Zhang, X. H.; Han, X. J.; Yan, M. Carbon footprint of China's crop production—An estimation using agro-statistics data over 1993–2007. *Agriculture Ecosystems & Environment*, **2011**, 142(3-4), 231–237. https://doi.org/10.1016/j.agee.2011.05.012.
40. Cheng, G. Data Envelopment Analysis: Methods and MaxDEA Software. Beijing: Intellectual Property Publishing House Co. Ltd, 2014. (In Chinese).
41. Pastor, J. T.; Lovell, C. A. K. A global Malmquist productivity index. *Economics Letters* **2005**, 88(2), 266–271. https://doi.org/10.1016/j.econlet.2005.02.013.
42. Oh, D. H. A global Malmquist-Luenberger productivity index. *Journal of Productivity Analysis* **2010**, 34(3),183–197. https://doi.org/10.1007/s11123-010-0178-y.
43. Jin T, Qian J X, Huang L Y, Nai J, Lu J F. Factor decomposition analysis for the step growth pattern in China's grain production. *Research of Agricultural Modernization*, **2016**, 37(3), 476-482. https://doi.org/10.13872/j.1000-0275.2016.0047(in Chinese).
44. Godfray, H. C. J.; Beddington, J. R.; Crute, I. R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J; Robinson, S.; Thomas, S.; Toulmin, C. Food security: The challenge of feeding 9 billion people. *Science* **2010**, 327(5967), 812-818. https://doi.org/10.1126/science.1185383.
45. General Office of the People's Government of Jiangsu Province. Implementation Plan for Promoting Cultivated Land Rotation and Fallowing for Green Agricultural Development in Southern Jiangsu Province as a Whole. http://www.jiangsu.gov.cn/art/2018/11/19/art_46144_7884154.html (In Chinese) .