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Research on the Relationship Between Technological Progress and Spatial Spillover of Agricultural Pollution: A Case Study of Yangling Agricultural High-Tech Industrial Demonstration Zone

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ABSTRACT

Technological progress is the key to promoting efficient agricultural production and an important means and fundamental approach to achieving high-quality agricultural development. This paper uses panel data from the Yangling Agricultural High-tech Industrial Demonstration Zone from 2010 to 2020 as an example, calculates the agricultural technological progress index from 1998 to 2018 based on the DEA-Malmquist index model, and finally explores the causal relationship between the two using a Two-way fixed effects model. The results show that the technological progress index of the Yangling Agricultural High-tech Industrial Demonstration Zone is on an upward trend; technological progress has a negative impact on agricultural pollution, that is, technological progress can inhibit the spatial spillover of agricultural pollution and relatively reduce environmental pollution. Therefore, there is a significant causal relationship between agricultural technological progress and the spatial spillover of agricultural pollution in the Yangling Agricultural High-tech Industrial Demonstration Zone. The region can start with technological progress, expand the scope of agricultural technology use and increase the utilization rate of high-tech agricultural machinery, which can reduce local and neighboring agricultural pollution to a certain extent and promote the healthy development of local agriculture.

KEYWORDS

Technological Progress, Agricultural Pollution, Spatial Spillover, Yangling Agricultural High-Tech Industrial Demonstration Zone.

1. INTRODUCTION

In recent years, many important reports in China have emphasized the need to "promote the construction of a beautiful China, adhere to the integrated protection and systematic management of mountains, rivers, forests, fields, lakes, grasslands, and deserts, coordinate industrial restructuring, pollution control, ecological protection, and climate change response, and synergize the promotion of carbon reduction, pollution reduction, green expansion, and growth, advancing ecological priority, conservation, intensification, green, low-carbon development." However, against the backdrop of economic globalization and the continuous growth of global population, the rapid expansion of the agricultural economy heavily relies on organic inputs such as pesticides and fertilizers. This has led to issues such as soil acidification and compaction, declining soil fertility, and severe pollution. At the same time, with rapid economic development and strengthened inter-regional connections, the spatial spillover of pollutants also urgently needs to be addressed. These issues run counter to the goal of building a beautiful China that people eagerly hope to achieve, seriously hindering the sustainable development of agriculture, endangering food security issues closely related to people's daily lives, and affecting people's sense of happiness and fulfillment in healthy living. Therefore, from a long-term perspective, strengthening pollution control is currently the primary measure for the country. For agriculture, improving pollution issues cannot ignore the power of technological progress, which is the primary driving force leading development and provides strong guarantees for the development of a green economy. At the same time, with economic development and the transfer and diffusion of technology, the spatial spillover effect of green technological progress in China's agricultural industry on pollution also needs to be recorded. From the perspective of sustainable agricultural development, technological progress is the key to promoting efficient agricultural production and an important means and fundamental approach to achieving high-quality agricultural development. As an agricultural demonstration zone, understanding the spatial impact of technological progress on pollution can help Yangling better balance high yield and environmental protection.

2. LITERATURE REVIEW

Based on domestic and international research, studies on technological progress are commonplace. Most scholars' findings confirm that technological progress can promote the development of green economy. Zheng Yi et al. believe that China's environmental governance has a latecomer advantage, and environmental technical efficiency is the most important factor in effectively managing environmental pollution[1]; Meng Wangsheng and Zhang Yang argue that natural resource endowments inhibit the improvement of regional green growth efficiency, and technological innovation, rather than technology introduction, is the main source of contribution to green economic growth[2]; Feng Rui points out that financial agglomeration affects green economic efficiency through the mediating effect of green technological innovation, and green technological innovation largely determines the improvement of green economic efficiency directly[3]; Chen Sihang et al. use provincial data from the Yangtze River Economic Belt as an example, and their research finds that green technological progress can positively promote the development of green economy in the long term[4]; He Xionglang and Bai Yu believe that technological progress plays a mediating role in the impact of environmental governance on regional green economic development performance, and technological progress can significantly promote the improvement of regional green economic development performance[5]; Yu Yan and Han Gang argue that technological progress can significantly help farmers increase their income and improve production and quality[6]; Zhang Xiaoli et al. believe that the overall quality of agricultural green development in major grain-producing areas is on an upward trend, and the core driving force is agricultural technological progress[7]. Many scholars also believe that local technological progress can improve environmental pollution in surrounding areas. Yan Guiquan et al. believe that agricultural non-point source pollution has obvious spatial agglomeration characteristics, and the positive impact of environmental pollution reduction brought by green technological progress is stronger[8]; Qian Juan believes that biased technological progress can directly reduce local environmental pollution and indirectly improve the environmental quality of neighboring areas, with spatial spillover effects on environmental pollution[9]; Gao Bo believes that the geographical correlation of urban economic activities causes technological innovation to produce spatial spillover effects, and promotes high-quality development of neighboring cities' economies through technology diffusion and other means[10].

In recent years, some scholars have begun to focus on the relationship between technological progress and agricultural pollution, conducting a series of path studies. Sun Yuzhu et al. believe that fully leveraging the technological efficiency of biochemical inputs is the key to solving the current food problem[11]; Hu Feifan and Li Yong argue that the transfer of rural labor has reduced the input of labor factors, which in turn can accelerate the substitution effect of capital, technology, and other factors[12]; Li Gang believes that China's rural labor population is experiencing oversupply, and the transfer of rural labor is conducive to enhancing food production capacity. The transfer of rural labor into the secondary and tertiary industries has optimized the national economic structure, driven sustained and rapid growth of the overall economy, and national prosperity will bring more financial resources back to agriculture, thus providing strong support for national food security[13]; Zhang Jia et al. argue that the transfer of rural labor alone has a certain promoting effect on food security, but due to the large number of high-quality laborers being transferred to the secondary and tertiary industries, when combined with agricultural technology, it has not effectively promoted safe food production and even inhibited production[14]; Zhang Qie, by comparing the technological paths of agricultural modernization in the United States and Japan, concludes that China's agricultural technological progress should choose a path of simultaneously advancing agricultural biotechnology and mechanical technology, and has achieved significant results to date[15].

Coincidentally, foreign scholars have been studying the relationship between technological progress and environmental pollution earlier. As early as 1990, Porter pointed out convincingly that energy conservation, emission reduction, optimization of energy structure, and technological change are inseparable[16]. Shunsuke Managi believes that technological changes have had a significant impact on the exploration, development, and production of oil and natural gas in the Gulf of Mexico over the past fifty years, and the negative effects of resource depletion and environmental regulation on the frontier of oilfield production have decreased over time[17]. Levinson argues that the improvement in environmental pollution in the US manufacturing industry stems from technological progress, rather than changes in imports or types of domestically produced goods[18]. Sisco and Pianta propose that the United States, Japan, and the European Union have invested heavily in scientific research and the development of energy conservation and emission reduction, achieving good environmental performance[19]. Zhang and Li believe that for a region to effectively achieve a high-efficiency green economy, the best approach is to improve technological innovation, urbanization, marketization, and environmental regulation[20]. The above research findings are relatively broad and do not reflect the relationship between technological progress and agricultural pollution in specific regions at the micro-scale. Based on this, this paper takes the Yangling Agricultural High-tech Industrial Demonstration Zone as an example for small-scale research, utilizing panel data from 2010 to 2020 and employing spatial econometric methods to conduct an in-depth study on the relationship between technological progress and spatial spillover of pollution, hoping to provide suggestions for the sustainable development of agriculture in the region.

3. RESEARCH METHODS AND DATA SOURCES

3.1. study area

The Yangling Agricultural High-tech Industrial Demonstration Zone (hereinafter referred to as the Yangling Demonstration Zone) is located in the central part of the Guanzhong Plain in Shaanxi Province. Covering a total area of 135 square kilometers, the Yangling Demonstration Zone has a permanent resident population of over 250,000. The zone is well-connected by transportation, with major trunk lines such as the Longhai Railway, Xulan High-speed Railway, and Lianhuo Expressway running east to west across the entire area. It is the first national-level agricultural high-tech industrial demonstration zone in China, governing the only county-level administrative district, Yangling District. Although nominally under the jurisdiction of Xianyang City, the actual administrative jurisdiction is exercised by the Yangling Demonstration Zone Management Committee. Within Shaanxi Province, the Yangling Demonstration Zone occupies an important position as a core area for agricultural science and technology research and promotion. It holds numerous honorary titles, including "National Food Safety Demonstration City" and "National Healthy Township (County)", which demonstrate the demonstration zone's excellent performance in food safety and sanitary environment. Relying on its agricultural technology advantages, the Yangling Demonstration Zone vigorously develops modern agriculture, agricultural science and technology research and promotion, agricultural product processing, and other industries. Through the dual-driven approach of technological innovation and institutional innovation, the demonstration zone has explored a path to reshape the rural industrial value chain with "new quality productivity" and formed multiple characteristic industrial clusters. The zone also houses science and education institutions such as Northwest A&F University and Yangling Vocational and Technical College, providing strong support for technological innovation and talent cultivation in the demonstration zone. In addition, the demonstration zone actively organizes agricultural high-tech achievement exhibitions, agricultural science and technology demonstration and promotion exhibitions, and other activities to promote the innovation and development of agricultural science and technology. At the same time, the demonstration zone also strengthens cooperation and exchanges with domestic and foreign scientific research institutions, continuously enhancing its own technological innovation capabilities.

3.2. research methods

It is common for existing research to utilize Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) to measure agricultural technological progress indices. However, DEA requires precise data and is susceptible to outliers; whereas SFA is a parametric estimation method that requires a known functional form and assumes the distribution of error terms, which increases the difficulty of model construction and parameter estimation, potentially requiring higher costs and time. Compared to traditional DEA models, the DEA-Malmquist index model mainly measures the static relative efficiency of different decision-making units during the same period, that is, the change in comprehensive technical efficiency. The Malmquist index model focuses on dynamic efficiency analysis over multiple periods, analyzing its directional changes in spatial dynamic efficiency, which can better reflect the dynamic changes in technological progress efficiency.

To examine the direct impact of technological progress on the spatial spillover effect of agricultural pollution, this paper uses panel data from 2010 to 2020 across the country as an example to establish a two-way fixed effects model to test the relationship between the development of digital inclusive finance and urban-rural income.

3.3. Variable description and data source

The following variable references are derived from Kong Fanbin's[21] research on agricultural ecological efficiency and Deng's[22] research on green technological progress in Chinese agriculture. The main variables are listed in the table below:

Tab 1 Variable Selection

Variable	Variable Name	Specific Indicator
Explanatory Variable	Agricultural Technological Progress	Number of patents, agricultural mechanization utilization rate
Dependent Variable	Agricultural Pollution	Quantity of chemical fertilizers, pesticides, waste stations, and treatment volume of sewage plants
Control Variables	Economic Development Level	Per capita GDP
	Urbanization Level	Urbanization rate (urban permanent population/total population)
	Human Capital Level	Permanent population / registered population

This article utilizes panel data from 2010 to 2020 for analysis. In the design of the data, the main explanatory variables include inputs such as the number of fertilizers, pesticides, garbage stations, and the treatment capacity of wastewater treatment plants. The dependent variables are measured by the number of patents and the utilization rate of agricultural mechanization. All the above data are sourced from the "China Rural Statistical Yearbook", "China Agricultural Statistical Yearbook", "China County Statistical Yearbook", "Shaanxi Statistical Yearbook", and "Xianyang Statistical Yearbook". Some missing data were calculated using interpolation based on the original data.

4. RESEARCH RESULTS

4.1. Measure the technological progress index

From the table below, it can be seen that the average value of Yangling Agricultural High-tech Industrial Demonstration Zone from 2010 to 2020 is 1.129, indicating that the productivity level after comprehensively considering factors such as land, labor, capital, and energy has shown an upward trend, with an overall increase of 12.9%. Among them, technical efficiency has shown an upward trend, indicating that more attention has been paid to the upgrading of agricultural high-tech in the agricultural production process, while the emphasis on efficiency improvement is slightly insufficient. Further decomposition of technical efficiency shows that scale efficiency has driven the improvement of technical efficiency, while pure technical efficiency has a negative impact on the growth of technical efficiency. From year to year, the green total factor productivity grew the fastest from 2017 to 2018, reaching 149.8%.

Tab 2 Technical progress index and its decomposition

year	EFFCH	TECH	FECH	SECH	TFPCH
2010—2011	1.008	1.055	1.004	1.004	1.064
2011—2012	1.023	1.014	1.013	1.010	1.037
2012—2013	1.002	1.140	1.007	0.995	1.143
2013—2014	0.994	1.010	0.999	0.995	1.005
2014—2015	0.988	1.074	1.006	0.982	1.061
2015—2016	1.006	1.173	0.984	1.021	1.179
2016—2017	0.944	1.215	0.945	0.999	1.148
2017—2018	1.032	1.452	1.096	0.942	1.498
2018—2019	0.941	1.163	0.952	0.989	1.094
2019—2020	0.980	1.103	0.914	1.072	1.081
mean	0.992	1.139	0.992	0.901	1.129

4.2. Two-way fixed effects model

The regression coefficient of the impact of technological progress on the spatial spillover of agricultural pollution is -0. 394, which is significant at the 1% level. This indicates that technological progress has a negative impact on agricultural pollution, meaning that technological progress can inhibit the spatial spillover of agricultural pollution and relatively reduce environmental pollution. The spatial spillover effect of economic development level on agricultural pollution is also negative, indicating that the former has a significant inhibitory effect on the latter. A possible reason is that as per capita GDP increases, people's demands for quality of life improve, and environmental awareness gradually strengthens, prompting governments and enterprises to increase environmental protection investment and reduce pollution emissions. At the same time, the improvement of economic level brings more advanced environmental protection technologies and more effective pollution control methods, which all contribute to reducing environmental pollution. Furthermore, the enhancement of economic strength enables regions to share environmental protection resources and technologies, thereby further inhibiting pollution through spatial spillover effects. The spatial spillover effect of urbanization level on green technological progress in surrounding areas is not significant. A possible reason is that economic development resources such as population and land in rural areas tend to concentrate in urban sectors, having little impact on other activities in other rural areas. There is a significant positive correlation between human capital and the spatial spillover of agricultural pollution. A possible reason is that the flow of human capital often accompanies the dissemination of knowledge, technology, and production methods. In agricultural production, farmers may bring efficient but highly polluting production methods to new areas, leading to the spatial diffusion of agricultural pollution. At the same time, regions with abundant human capital may attract more agricultural investment and production activities, which, if not properly managed environmentally, may also exacerbate local agricultural pollution. Therefore, while the spatial flow of human capital promotes agricultural production and economic growth, it may also bring about spatial spillover of agricultural pollution.

Table 3 Regression results of Two-way fixed effects model

Variable	(1) Agricultural pollution index	(2) Agricultural pollution index	(3) Agricultural pollution index	(4) Agricultural pollution index
Agricultural Technological Progress	-0.323***	-0.345***	-0.357***	-0.394***
	(0.258)	(0.269)	(0.270)	(0.301)
Economic Development Level		-0.214***	-0.217***	-0.220***
		(0.026)	(0.021)	(0.022)
Urbanization Level			0.438	0.499
			(0.047)	(0.046)
Human Capital Level				0.634***
				(0.083)
Time fixed effect	YES	YES	YES	YES
individual fixed effect	YES	YES	YES	YES
N	203	203	203	203
R2	0.623	0.635	0.658	0.659

Note: * P<0.10， *** P<0.01， values in parentheses are Z-values.

5. CONCLUSION

This article utilizes panel data from the Yangling Agricultural High-tech Industrial Demonstration Zone spanning from 2010 to 2020 as an example. Based on the DEA-Malmquist index model, it calculates the agricultural technological progress index from 2010 to 2020. Finally, it employs a Two-way fixed effects model to explore the causal relationship between the two. The following results are obtained:

(1) The technological progress index of Yangling Agricultural High-tech Industrial Demonstration Zone shows an upward trend, indicating that more attention is paid to the upgrading of agricultural high-tech in the agricultural production process, while the emphasis on efficiency improvement is slightly insufficient.

(2) The regression analysis of the spatial spillover effect of technological progress on agricultural pollution reveals that the regression coefficient for the impact of technological progress on the spatial spillover of agricultural pollution is -0. 394, which is significant at the 1% level. This indicates that technological progress has a negative impact on agricultural pollution, meaning that technological progress can inhibit the spatial spillover of agricultural pollution and relatively reduce environmental pollution. The spatial spillover effect of economic development level on agricultural pollution is negative. The spatial spillover effect of urbanization level on green technological progress in surrounding areas is not significant. There is a significant positive correlation between human capital and the spatial spillover of agricultural pollution.

Based on this, the region can further strengthen technical measures, enhance agricultural technology, protect the environment, and increase agricultural production. On the other hand, it is also necessary to vigorously develop the economy and improve economic levels, so that regions can share environmental protection resources and technologies, thereby further suppressing pollution through spatial spillover effects.

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