



# Spatial interaction effects on the relationship between agricultural economic and planting non-point source pollution in China

Xin Li<sup>1</sup> · Jie Shang<sup>1</sup>

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## Abstract

Solving the contradiction between agricultural economic growth and agricultural environmental problems is a difficult problem in regional environmental governance. Based on the panel data of 31 provinces, municipalities, and autonomous regions in China from 2000 to 2019, spatial Dubin model (SDM) is used to analyze the influence of agricultural economic growth and other factors on planting non-point source pollution. Innovate from the perspective of research objects and research methods, and the research results show (1) In the past 20 years, the amount of fertilizer applied and crop straw yield increased continuously. Through the fertilizer and farmland solid waste discharge of ammonia nitrogen ( $\text{NH}_3\text{-N}$ ), total nitrogen (TN), total phosphorus (TP), and chemical oxygen demand (COD), calculation of the equal-standard discharges of planting non-point source pollution shows that China's planting non-point source pollution is serious. Among the investigated areas in 2019, the equal-standard discharges of planting non-point source pollution in Heilongjiang Province were the highest and have reached  $24.35 \times 10^{10} \text{ m}^3$ . (2) The global Moran index of 20 years in the study area shows obvious spatial aggregation and diffusion characteristics, and has a significant positive global spatial autocorrelation, indicating that planting non-point source pollution discharges of the study area have potential interdependence in space. (3) SDM time-fixed effect model showed that the equal-standard discharges of planting non-point source pollution had a significant negative spatial spillover effect, and the spatial lag coefficient was  $-0.11$ . Among the influencing factors, agricultural economic growth, technological progress, financial support to agriculture level, consumption capacity, industrial structure, and risk perception have significant spatial spillover effects on planting non-point source pollution. The results of effect decomposition show that the positive spatial spillover effect of agricultural economic growth on adjacent areas is greater than the negative effect on the local area. Based on the analysis of significant influencing factors, the paper provides direction guidance for the formulation of planting non-point source pollution control policy.

**Keywords** Planting non-point source pollution · Agricultural economic growth · Temporal and spatial differentiation · Spatial relevance · Spatial Dubin model

## Introduction

According to the statistics of the World Bank, China ranks as the world's first with a population of over 1.4 billion in 2020.<sup>1</sup> In 2018, China's arable land area is  $119.49 \times 10^4$  hectares, accounting for only 8.57% of the world's total arable

land.<sup>2</sup> The per capita arable land in China is far below the world average level. At the same time, with the continuous improvement of living standards, the continuous upgrading of consumption structure, the growing demand for high-quality, green, nutritious, and healthy food products, China's grain supply and demand in a tight balance state, so agricultural production is facing huge challenges to alleviate this situation. To solve the problem of China's food security and build a new development pattern with the domestic big cycle as the main body and the mutual promotion of domestic and international double cycles, a good agricultural resource environment is not only a necessary condition for maintaining China's agricultural sustainable production but also the pivotal conditions for ensuring world food security. Planting non-point source pollution refers to the pollution of water, soil, air, and agricultural products caused

<sup>1</sup> <https://data.worldbank.org.cn/indicator/SP.POP.TOTL?end=2020&start=2020&view=map>

<sup>2</sup> <https://data.worldbank.org.cn/indicator/AG.LND.ARBL.HA?end=2018&start=1961&view=chart>

Responsible Editor: Philippe Garrigues

✉ Xin Li  
hello\_o\_o@nefu.edu.cn

<sup>1</sup> College of Economy and Management, Northeast Forestry University, Harbin 150040, Heilongjiang, China

by pollutants generated in the process of crop production without reasonable disposal. The main sources are fertilizers, pesticides, and agricultural film residues in cultivated land which are lost due to unreasonable use in agricultural production. Among them, the chemical elements such as nitrogen and phosphorus that are not absorbed by crops in planting production activities cause water pollution in the form of organic matter or inorganic matter through surface runoff and underground infiltration, which is one of the important sources of agricultural non-point source pollution. It is closely related to the sustainable development of agriculture in a nation and a region.

According to the statistics of China Statistical Yearbook and China rural statistical yearbook, the total output value of agriculture, forestry, animal husbandry, and fishery in China was 2.49 trillion yuan in 2000, accounting for 14.7% of GDP, of which agriculture accounted for 55.68%. In 2015, the gross output value of China's agriculture, forestry, animal husbandry, and fishery exceeded 10 trillion yuan for the first time, accounting for 8.4% of the GDP, of which agriculture accounted for 53.2%. In 2019, the total output value of agriculture, forestry, animal husbandry, and fishery increased to 12.39 trillion yuan, accounting for 7.1% of GDP, of which the agricultural output value accounted for 53.29% of the total output value of agriculture, forestry, animal husbandry, and fishery.<sup>3</sup> Since China's reform and opening up, with the rapid development of the secondary and tertiary industries, the proportion of the GDP in the GDP has decreased. However, the total output value of agriculture, forestry, animal husbandry, and fishery maintained a steady growth trend, and the agricultural output value accounted for more than 50% of the total output value of agriculture, animal husbandry, and fishery, which shows that agriculture occupies an important position in the national economy. Agricultural economy has made outstanding contributions to the transition of the market economy, and natural resources and agricultural ecological environment have also paid a high price for it. Agricultural non-point source pollution has become increasingly serious. The Second China Pollution Source Census Announcement shows that in 2017, China's agricultural source of water pollutant discharges, the amount of ammonia nitrogen, total nitrogen, and total phosphorus in the water pollution of planting industry are 83,000 t, 719,500 t, and 76,200 t. Meanwhile, the announcement shows that in 2017, China's straw production is 805 million t, straw can be collected 674 million tons of resources, and straw utilization of 585 million t.<sup>4</sup> According to the data released by China's Ministry of Agriculture and Rural Affairs, the

national average straw comprehensive utilization rate has reached 84%, and the national average fertilizer application intensity is 373.5 kg/ha, which is about 3.11 times higher than the global average.<sup>5</sup> Planting non-point source pollution has evolved from traditional single-channel pollution to a three-dimensional pollution pattern, and the task of prevention and control is arduous and faces huge challenges. Based on China's national conditions, vigorously promoting the development of agriculture is a necessary condition to ensure national food security, and planting non-point source pollution is one of the core problems that need to be solved urgently. The planting production environment is closely related to the development of agricultural production. As agriculture is an important basis of the national economy, the prevention and control of planting non-point source pollution have an important impact on the development of the agricultural economy. At the same time, with the introduction of support and preferential policies for farmers, the industrial structure has been further optimized, and the basic role of agriculture has become increasingly apparent. The change of planting non-point source pollution will inevitably affect agricultural economic growth, and the relationship between planting non-point source pollution and China's agricultural economic growth is an important research direction in this paper.

In 2013, China's agricultural non-point source pollution prevention and control policies entered the stage of systematic establishment (Shi and Shang 2021). The Opinions of the CPC Central Committee and the State Council on Implementing the Rural Revitalization Strategy, the Implementing Plan for the Control and Supervision of Agricultural Non-point Source Pollution (for Trial Implementation), and other documents were put forward. This reflects China's determination to "ensure agricultural economic growth and avoid environmental costs." Many programmatic documents have raised the issue of optimizing the economic structure and preventing and controlling agricultural non-point source pollution. As a developing country, how to coordinate agricultural economic growth and the agricultural environment is one of the keys to realize China's economy from "extensive" high-speed growth to "intensive" high-quality development.

Based on the above background, this paper attempts to explore the way to prevent and control planting non-point source pollution in China and further promote the implementation of agricultural non-point source pollution control policies. Through the analysis of panel data of 31 provinces, municipalities and autonomous regions (excluding Hong Kong, Macao, and Taiwan) in China from 2000 to 2019, the paper selects two dimensions of time and space to clarify the current situation of planting non-point source pollution in China, explores the internal spatial interaction of

<sup>3</sup> <http://www.stats.gov.cn>

<sup>4</sup> [https://www.mee.gov.cn/home/ztbd/rdzl/wrypc/zlxz/202006/t20200616\\_784745.html](https://www.mee.gov.cn/home/ztbd/rdzl/wrypc/zlxz/202006/t20200616_784745.html)

<sup>5</sup> [http://www.ghs.moa.gov.cn/ghgl/202105/t20210521\\_6368121.htm](http://www.ghs.moa.gov.cn/ghgl/202105/t20210521_6368121.htm)

planting non-point source pollution among provincial units, and analyzes the relationship between agricultural economic growth and planting non-point source pollution by spatial econometric models. Starting from the relationship between the different influencing factors of planting non-point source pollution prevention and agricultural economic growth, the paper provides a decision-making basis for the formulation of planting non-point source pollution prevention and control policies, and promotes the sustainable development of China's agricultural production environment and agricultural economic growth.

## Literature review

### Research on agricultural non-point source pollution

The research on agricultural non-point source pollution covers a wide range, mainly including the following stages. First, the source, current situation, and harm of agricultural non-point source pollution were studied, which aroused the attention of the society on this issue, and promoted the research on agricultural non-point source pollution. Research shows that agricultural non-point source pollution has posed a serious threat to the global environment, and it is urgent to solve the problem of agricultural non-point source pollution. With the rapid development of agriculture all over the world, artificial nitrogen and phosphorus discharges such as fertilizer application and plant nitrogen fixation have become the main factors of the global nitrogen cycle and phosphorus cycle. Excessive discharges of nitrogen and phosphorus will lead to an increased risk of eutrophication and growth of anoxic zones in coastal waters (Withers and Jarvie 2008; Swaney et al. 2012, 2015; Hu et al. 2020), while nutrient pollution is the third major threat to the Earth after biodiversity loss and climate change (Giles 2005; He et al. 2019). Second, study and analyze the influencing factors of agricultural non-point source pollution. Agricultural mechanization, new irrigation technology, and the use of agrochemical have contributed to the exponential growth of agricultural production and agricultural waste in many countries. Improper disposal of crop waste has aggravated agricultural non-point source pollution (Tao et al. 2010; Bhuvaneshwari et al. 2019; Wang et al. 2019; Sherwood 2020). Third, the evaluation and forecast research on emissions of non-point source pollution. The agricultural non-point source pollution simulation model is constructed from farmland scale and watershed scale to evaluate the current situation of agricultural non-point source pollution, predict the development of agricultural non-point source pollution, and discuss the problem of agricultural non-point source pollution control (Wang et al. 2007; Ma et al. 2012; Sheng et al. 2018). Fourth, study the relevant prevention and

control policies of agricultural non-point source pollution. The study analyzed the evolution of agricultural non-point source pollution management system and policy, analyzed the problems in the management policy, and put forward policy recommendations to prevent and control agricultural non-point source pollution (Zhou 2010; Niu et al. 2022).

### Research on the relationship between pollution and economic growth

The consumption of life and production on the environment has brought rapid economic development (Feng et al. 2021). Scholars began to pay attention to how to balance the relationship between economic growth and environmental protection, and demonstrated the relationship between economic growth and pollution from many aspects. For example, the environmental Kuznets curve (EKC) hypothesis has verified the relationship between environmental pollution and economic growth, which is characterized by an “inverted U” curve that rises first and then falls. Before economic development reaches a certain level, economic growth will be accompanied by the increase of environmental pollution, and then environmental pollution will be improved along with economic growth (Grossman and Krueger 1992). This hypothesis provides a new way for scholars to study the relationship between pollution and economic growth. Some scholars verified the relationship between environmental pollution and economic growth by selecting different pollution discharge indicators (Shen and Zhang 2015; Sun et al. 2016; Destek and Sarkodie 2018; Shang et al. 2019; Shi and Chen 2019; Liu and Xu 2021). On the basis of many researches, some scholars began to demonstrate the relationship between environmental pollution and economic growth by choosing different research methods or research objects, and the demonstration results were not completely unified. For example, using the decoupling index method to analyze the relationship between agricultural economy and agricultural pollution in Chengdu, Sichuan, China, the results showed that the use of pesticides and fertilizers has been decreasing with the development of agricultural economy (Li et al. 2019). Through the study of the impact of the relationship between agriculture, economic growth, and renewable energy on carbon dioxide emissions, it is verified that the EKC relationship exists in the whole sample economies and developing economies, and economic growth only has a positive impact on CO<sub>2</sub> emission in developing economies (Qiao et al. 2019). The relationship between agriculture non-point source pollution and economic development in the Three Gorges Reservoir area was tested by using agricultural input and agricultural waste output. The results showed that the relationship between agricultural input (consumption of chemical fertilizer, pesticide, and agricultural film) and economic growth satisfies EKC, while the relationship between agricultural waste output (grain residue and livestock manure) and

economic growth is inconsistent with EKC hypothesis (Tong et al. 2016). In recent years, some scholars have verified that agricultural non-point source pollution discharges have obvious spatial correlation, and proposed that the spatial dependence of agricultural environment should be listed as one of the factors affecting economic growth (Yang et al. 2012; Liu et al. 2015; Chen et al. 2016; Wu et al. 2016; Zhang et al. 2018; Qiu et al. 2021). Based on this, some scholars considered the relationship between agricultural pollution and agricultural economic growth. And the results showed that there is an obvious spatial spillover effect between them (Yu et al. 2017; Cao et al. 2021; Zhu et al. 2021). The results provide a new direction for exploring the relationship between planting non-point source pollution and agricultural economic growth and for formulating relevant policies.

### General comment

From the existing research, there are many verification studies on the relationship between pollution and economic growth, but there are still some problems that can be improved. First of all, planting non-point source pollution is one of the important sources of agricultural non-point source pollution, but there is a lack of research on agricultural non-point source pollution from the planting perspective. Secondly, there is little research on agricultural non-point source pollution and agricultural economic growth, and the existing research on agricultural non-point source pollution is relatively broad or too single and lack of planting non-point source pollution and agricultural economic-related research. Thirdly, most of the existing studies on the relationship between agricultural non-point source pollution and agricultural economic growth are verified by EKC by selecting different pollution indicators and influencing factors. However, the conclusion of the study is not completely consistent, and the reasons for the differences may be related to spatial factors. Therefore, it is suggested to add spatial factors to verify the relationship from the two dimensions of space and time. Based on this, the research object and research method are improved simultaneously. The research object aspect selects planting non-point source pollution in the agricultural non-point source pollution, can be more detailed study the relationship between planting non-point source pollution and agricultural economy, more clearly for planting non-point source pollution prevention and control to provide countermeasures and suggestions. In terms of research methods, spatial factors are added to analyze the spatial effect between planting non-point source pollution discharges and economic growth, which provides a new perspective. In summary, the following questions are raised in this paper: What is the current situation of planting non-point source pollution in China? Under the influence of spatial

factors, what is the relationship between planting non-point source pollution and agricultural economic growth? How to put forward practical and feasible countermeasures to prevent planting non-point source pollution?

## Material and methodology

### Research area

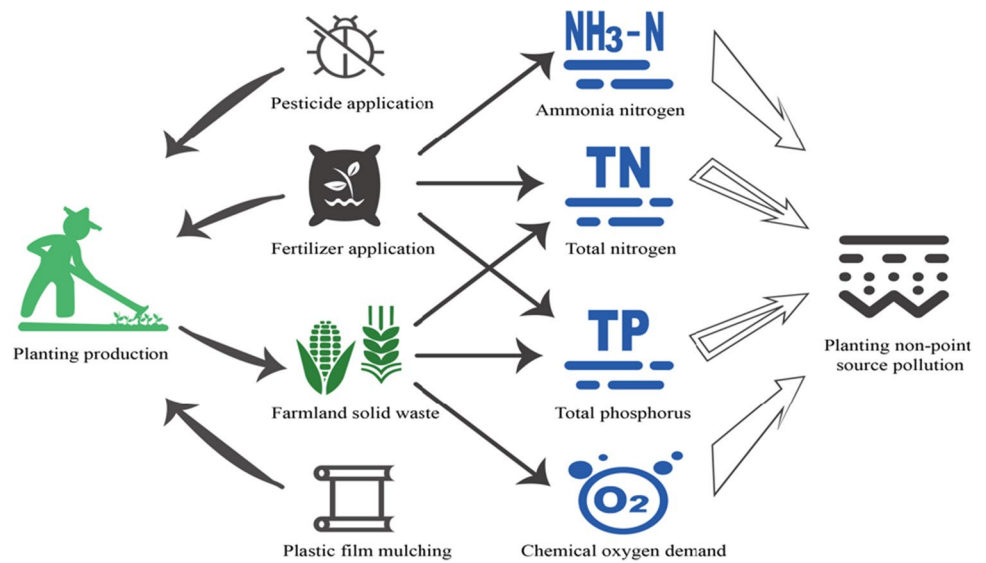
China has a vast territory, wide topographic height difference, diverse hydrothermal conditions, and different crop ripening systems. But with the development of the social economy in China, the limited factors of agricultural resources and agricultural environment are becoming more and more serious. In 2015, China's arable land area was  $1.35 \times 10^8$  ha, high quality and advanced cultivated land only accounts for 29.4% of the total cultivated land area, and the reserve resources of cultivated land for development and utilization are only  $2.2 \times 10^6$  ha. The total amount of agricultural water in China is insufficient, with per capita water resources of only 2 034 m<sup>3</sup>, less than 1/4 of the world's per capita water resources. Excessive use of agricultural chemicals and insufficient utilization of agricultural waste resources have caused serious water pollution and a wide range of non-point source pollution. China's agricultural resources and environment are generally overloaded, with a shortage of cultivated land and water resources and poor quality. Natural disasters often occur in various regions, and agricultural environmental problems are exacerbated. At the same time, China's regional socio-economic development levels are different, and the limiting factors of agricultural resources and the constraints of agricultural environment are different in different regions. For a long time, China's extensive agriculture management mode of "emphasizing production and neglecting protection" has brought about economic growth, but caused serious damage to agricultural resources and the environment. In recent years, the aggravated aging of the rural labor force and the increase of agricultural production costs also make agricultural production in an unstable, unsafe, and unsustainable state, which has increased the burden of the agricultural environment (Shi et al. 2018).

### Research methods and data sources

#### Equal-standard discharge of planting non-point source pollution

The main sources of planting non-point source pollution include chemical fertilizer, pesticides, plastic film, and solid

**Fig. 1** Planting non-point source pollution discharge relationship



waste (Lai et al. 2004). The major pollutants discharged from the pollution sources are ammonia nitrogen (NH<sub>3</sub>-N), total nitrogen (TN) and total phosphorus (TP), and chemical oxygen demand (COD), and the formation process of planting non-point source pollution is shown in Fig. 1. For the above four non-point source pollutants, the use of pesticides and plastic films contributed less to their discharge (Yu et al. 2015; Liu et al. 2021); their usage is not included in the subsequent analysis. In this study, the non-point source pollution discharges of planting start from fertilizer and farmland solid waste; fertilizer pollution discharges are mainly selected nitrogen fertilizer, phosphate fertilizer, compound fertilizer to calculate the net amount. The discharge of farmland solid waste is calculated mainly according to the yield of paddy, wheat, corn, beans, potato, peanut, and rapeseed.

According to planting non-point source pollution source discharges calculated corresponding pollutant discharges. The main pollutants emitted from fertilizer sources are TN, TP, and NH<sub>3</sub>-N (Formula 1). In Formula (1), where *g* stands for region *g*. *T<sub>gm</sub>* refers to the discharge of pollutants (*t*) of fertilizer. *A<sub>g</sub>* refers to the acreage of crops (hm<sup>2</sup>). *ρ<sub>gm</sub>* refers to fertilizer discharges *m* pollutant discharge factor (kg/hm<sup>2</sup>). *f<sub>gm</sub>* is the amount used per unit area of nitrogen-containing fertilizers (phosphate-containing fertilizers) for crop cultivation (kg). *F<sub>g0</sub>* refers to the amount of nitrogen (phosphorus) fertilizer used per unit area for crop production in 2017 (kg/hm<sup>2</sup>). The main discharge pollutants of farmland solid waste are TN, TP, and COD (Formula 2). In Formula (2), *t<sub>gj</sub>* refers to the amount of pollutant emitted by crops (*t*), *q<sub>gi</sub>* refers to yield of the first crop (kg), and *m<sub>gi</sub>* means the coefficient of straw output of the second crop (kg/kg). *T<sub>i</sub>* refers to the collectible coefficient of crop straws for the *i*-th crop (%), and *φ<sub>i</sub>* refers to the discharge coefficient of the *i*-th pollutant of the crop (kg/t).

$$T_{gm} = A_g \cdot \rho_{gm} \cdot \frac{f_{gm}}{f_{g0}} \times 10^{-3} \tag{1}$$

$$T_{gi} = \left[ \sum_i q_{gi} \cdot m_{gi} (1 - t_i) \right] \cdot \varphi_i \tag{2}$$

In order to quantify and evaluate the economic and environmental impacts of different planting non-point source pollution on a uniform scale, the equivalent standard pollution load method was applied to standardize the pollutant discharge of the planting non-source pollution (Wu et al. 2017). The main formula is as follows:

$$P_{ij} = \frac{M_{ij}}{C_{oj}} \times 10^3 \tag{3}$$

$$P_j = \sum_{i=1}^n P_{ij} \tag{4}$$

In Formula (3), *P<sub>ij</sub>* is equal-standard pollution discharge of the *j*-th pollutant from the *i*-th pollution source in a certain area(m<sup>3</sup>/a). *M<sub>ij</sub>* is the discharge of the *j*-th pollutant from the *i*-th source (kg). *C<sub>oj</sub>* is the evaluation criterion for the *j*-th pollutant (mg/L). In Formula (4), *P<sub>j</sub>* is the total equal-standard pollution discharge of the *j*-th pollutant in a certain area, and *n* is the number of pollution sources in the area.

**Spatial correlation of planting non-point source pollution**

Exploratory spatial data analysis (ESDA) is an important technique in spatial econometrics (Laurent et al. 2012; Ye and Rey 2013). Using ESDA to explore the regional structure of



the characteristics of planting non-point source pollution discharges from inter-provincial, and calculate the global Moran index (Moran’s *I*) to measure the spatial cluster correlation of planting non-point source pollution variables between provinces in China. Moran’s *I* is calculated as follows:

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n (X_i - \bar{X})(X_j - \bar{X})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}} \tag{5}$$

$$S^2 = \frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n} \tag{6}$$

$$\bar{X} = \frac{\sum_{i=1}^n X_i}{n} \tag{7}$$

In Formula (5),  $X_i, X_j$  are the observed values of area  $i$  and area  $j$ , and  $i \neq j, n$  is the total number of areas.  $W_{ij}$  is the spatial weight matrix. In this study, geographical distance weight is selected to describe the spatial adjacency relationship between regions. According to the longitude and latitude of each regional capital, the distance between adjacent regions is calculated to construct the spatial weighting matrix. The result interval of the global Moran index is  $[-1, 1]$ . When the results pass the significance test, if  $I \in (0, 1]$ , it shows that the characteristics of planting non-point source pollution discharges are positively correlated between provinces, and the more the value tends to 1, the stronger the correlation is. If  $I \in [-1, 0)$ , it shows that there is a negative correlation between the characteristics of planting non-point source pollution in provinces, and the more the value tends to  $-1$ , the stronger the correlation is. If  $I = 0$ , it shows that the characteristics of planting non-point source pollution in the provinces are spatially independent.

**Construction of spatial econometric models**

Spatial Dubin model (SDM) is a commonly used spatial econometric model in spatial panel regression. It is characterized by considering both the spatial lag effect and the error effect of the interpreted variable and the explanatory variable. It is a more general form of the spatial hysteresis model (SLM) and the spatial error models (SEM) (Lesage and Pace 2009; Elhorst 2021). Its general expression is as follows:

$$Y = \rho WY + \beta X + \theta WX + \varepsilon; \varepsilon \sim (0, \sigma^2 I_n) \tag{8}$$

$$\varepsilon = \lambda W\varepsilon + \mu \tag{9}$$

In Formula (8) and Formula (9),  $Y$  and  $X$  are explained variables and explanatory variables respectively.  $\beta$  and  $\theta$  are the coefficients to be estimated.  $W$  denotes spatial weight matrix.  $\rho$  represents the spatial lag coefficient.  $\varepsilon$  is the independent and identically distributed random error term.  $\lambda$  is the coefficient of the space residual term. In this paper, a spatial econometric model of planting non-point source pollution and agricultural economic growth is constructed based on the spatial Dubin model, so as to explore the spatial effects of various driving factors under the influence of spatial effects.

Assume that some economic activities in a region can not only have an expected impact on the region, but also have an impact on neighboring regions due to its spatial dependence and spatial heterogeneity. Based on this, a spatial Dubin model of the relationship between planting non-point source pollution discharges and agricultural economic growth was constructed. The SDM model was calculated as follows:

$$\begin{aligned} \ln P_{it} = & \rho W \ln P_{it} + \beta_1 \ln pGap_{it} + \beta_2 \ln pce_{it} + \beta_3 \ln ei_{it} + \beta_4 \ln ms_{it} + \beta_5 \ln pi_{it} \\ & + \beta_6 \ln fs_{it} + \beta_7 \ln di_{it} + \beta_8 \ln ap_{it} + \theta_1 W \ln pGap_{it} + \theta_2 W \ln pce_{it} \\ & + \theta_3 W \ln ei_{it} + \theta_4 W \ln ms_{it} + \theta_5 W \ln pi_{it} + \theta_6 W \ln fs_{it} + \theta_7 W \ln di_{it} \\ & + \theta_8 W \ln ap_{it} + \varepsilon_{it} \end{aligned} \tag{10}$$

Among them,  $\ln P_{it}$  is the explained variable.  $\ln pGap_{it}, \ln pce_{it}, \ln ei_{it}, \ln ms_{it}, \ln pi_{it}, \ln fs_{it}, \ln di_{it},$  and  $\ln ap_{it}$  are all explanatory variables. The specific meanings of the explained variables and explanatory variables are shown in Table 1.  $i$  is the  $i$ -th region among the 31 regions in the country, and  $t$  is the year.  $W$  is the spatial weight matrix calculated by geographical distance.  $\varepsilon$  is the random perturbation term, obeys the normal distribution.  $\rho$  represents the spatial lag coefficient.  $\beta$  is the regression coefficient of explanatory variable.  $\theta$  is the regression coefficient of the spatial lag term of the explanatory variable.

The interpreted variable is the unit equal-standard pollution discharge of planting non-point source pollution. Explanatory variable: GDP per capita as a characterization of agricultural economic growth indicators, variable inflation treatment (CPI index 2000=100). The consumption power is expressed by rural per capita consumption expenditure, which is directly related to the purchasing power of agricultural products in agricultural production. The variable is treated as inflation (Rural resident price consumption index 2000=100). The technical progress is expressed by the effective irrigation rate and the intensity of agricultural machinery input per unit. Risk perception is expressed in terms of unit pesticide use intensity. The level of financial support for agriculture is the ratio of the total expenditure of agriculture, forestry, and water to the total agricultural production. The disaster situation is expressed by the ratio of the disaster area to the total sown area. The industrial structure is expressed as the ratio of gross agricultural product to gross domestic product. Logarithmic processing of all variables is to ensure the stability of data.

**Table 1** Variable index selection

Index selection	Variable definition	Unit	Symbol
Pollution degree	Unit equal-standard discharge = Total equal-standard discharge of pollutants/total sown area	m <sup>3</sup> /hm <sup>2</sup>	<i>P</i>
Agricultural economic growth	Per capita agricultural GDP = agricultural GDP/population at the end of the year	yuan	<i>pGap</i>
Consumption capacity	Rural per capita consumption expenditure	yuan	<i>pce</i>
Technical progress	(a) Effective irrigation rate = effective irrigation area/total sown area	%	<i>ei</i>
	(b) Unit input intensity of agricultural machinery = total power of agricultural machinery/total sown area	kW/hm <sup>2</sup>	<i>ms</i>
Risk perception	Unit pesticide use intensity = total pesticide use/total sown area	kg/hm <sup>2</sup>	<i>pi</i>
Financial support	Financial support for agriculture = agriculture, forestry, and water expenditure/agricultural GDP	%	<i>fs</i>
Disaster situation	Affected proportion = affected area/total sown area	%	<i>di</i>
Industrial structure	Agricultural proportion = agricultural GDP/GDP	%	<i>ap</i>

**Data sources**

The paper selected panel data from 2000 to 2019 of 31 provinces, municipalities, and autonomous regions (excluding Hong Kong, Macao, and Taiwan) in China which from the China Statistical Yearbook and the Chinese Rural Statistics Yearbook. The ratio of N, P, and K fertilizers in the agricultural compound fertilizer is not indicated in the statistical yearbook. Therefore, according to the sales situation of agricultural general compound fertilizer in the market and relevant literature, the ratio of N, P, and K fertilizer in agricultural compound fertilizer was converted according to 1:1:1 (Liu 2014). The yield coefficient, collectible coefficient, and pollution coefficient of straw were obtained through extensive literature investigation and comprehensive comparison (Song et al. 2018; Tao et al. 2019). The pollutant discharge coefficient of fertilizer mainly refers to the parameter value of the Ministry of Ecological Environment “Manual of Accounting Methods and Coefficient of Discharge Source Statistical Investigation.” As the state has not yet formulated relevant discharge standards for planting non-point source pollution, in this paper, the threshold concentrations of COD, NH<sub>3</sub>-N, TN, and TP are all adopted the V standard of “Environmental Quality Standard of Surface Water” (GB3838-2002). The corresponding standards for COD, NH<sub>3</sub>-N, TN, and TP are 40 mg/L, 2.0 mg/L, 2.0 mg/L, and 0.4 mg/L, respectively.

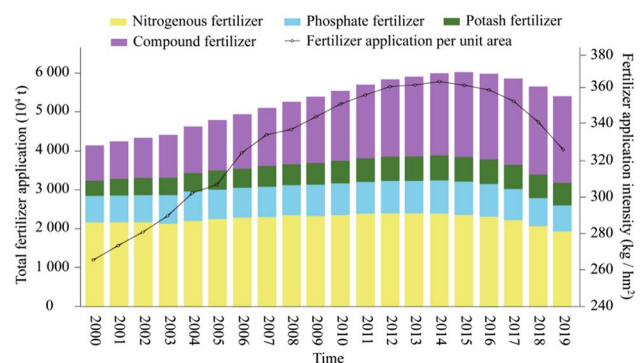
**Results**

**Status of planting non-point source pollution**

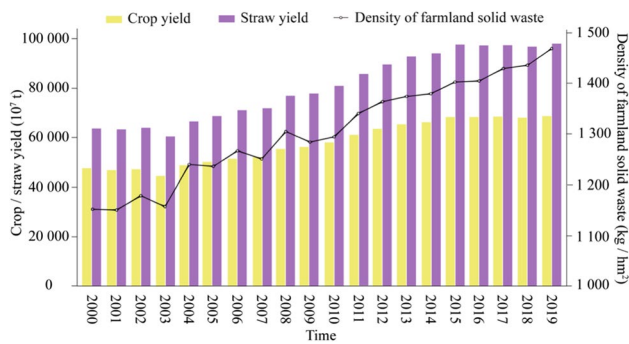
**Status of pollution source discharge**

The total amount of chemical fertilizer application in China has increased year by year since 2000, reaching a peak of 60.23 million t in 2015, and then began to decrease year by

year. The total amount of fertilizer application in China is 54.04 million t in 2019 (Fig. 2). The total amount of fertilizer applied in 2019 increased by 30.33% compared to 2000 and decreased by 10.28% compared with 2015. The average fertilizer application intensity in China in 2019 is 325.68 kg/hm<sup>2</sup>. However, it is still higher than the international warning standard of 225 kg/hm<sup>2</sup> for fertilizer input; the only areas below the warning standard are Heilongjiang, Jiangxi, Guizhou, Tibet, Gansu and Qinghai. Since China’s reform and opening up, the rapid development of industry has been driven by agriculture in the early stage, and the demand for chemical fertilizers in crop production has increased. At the same time, because China’s fertilizer utilization rate is low, the technical calculation of China’s grain fertilizer utilization rate in 2018 is 31%, which is far lower than the average level of agricultural developed countries (Wang et al. 2018), so the amount of fertilizer application shows a continuous increase stage. With the rapid development of industry, industrial development has gradually fed back to agriculture; the fertilizer application technology and utilization rate have been improved. At the same time, due to the gradual attention paid to agricultural non-point source



**Fig. 2** Fertilizer application and discharge intensity in China from 2000 to 2019



**Fig. 3** Crop yield, straw yield, and farmland solid waste discharge density in China from 2000 to 2019

pollution, a number of agricultural non-point source pollution prevention and control policies have been proposed, the amount of chemical fertilizers has been effectively controlled and began to show a decreasing trend.

The solid waste of farmland mainly comes from the stacking of farmland straw, and the continuous increase of crop yield leads to the continuous increase of straw yield, which also means that the discharge of solid waste from farmland increases with it. From 2000 to 2009, the crop yield basically showed a steady increase, and the density of farmland solid waste showed a “fluctuating” upward trend. After 2009, the density of farmland solid waste continued to rise, and in 2019, the density of farmland solid waste has increased to 1467.69 kg/hm<sup>2</sup> (Fig. 3). China’s cultivated land is scattered, the terrain varies greatly, and the scale of agricultural production is still in the stage of development. Affected by these factors, the collection and return of crop straw to the field and other links cannot completely rely on large-scale machinery, while the supervision of straw burning is increased, and the problem of crop straw accumulation still exists, which brings the problem of farmland solid waste pollution. The continuous increase of farmland solid waste density will inevitably lead to the increase of planting non-point source pollution discharges. However, the impact of agricultural solid waste accumulation has not been paid enough attention.

### Status of pollutants discharge

Calculate the equal-standard discharges of planting non-point source pollution in the survey area from 2000 to 2019, and select the spatial distribution of the equal-standard discharges in the survey area in 2000 and 2019 for comparison, as shown in Fig. 4. Comparing the overall spatial distribution of equal-standard pollution discharge of planting non-point source pollution in 2000 and 2019, it can be found that the distribution of pollution discharge in the investigated area was uneven and showed the trend of pollution aggravation and scope diffusion. In 2000, blue and green accounted for

the largest proportion in the distribution of equal-standard discharges in the investigated areas, and the areas with high discharges showed significant spatial aggregation characteristics. The distribution of equal-standard discharges changed significantly in the surveyed areas in 2019, with a total of 18 areas changed the distribution colors. The total area of blue representing lower discharges has decreased significantly, and the green distribution areas have also changed at the same time, but the total area generally remained stable. Yellow, purple, and red areas representing higher discharges increased to varying degrees, and the top five regions of equal-standard discharge are mainly China’s major agricultural provinces, namely Heilongjiang, Henan, Sichuan, Anhui, and Hubei (ranked from highest to lowest by equal-standard discharge).

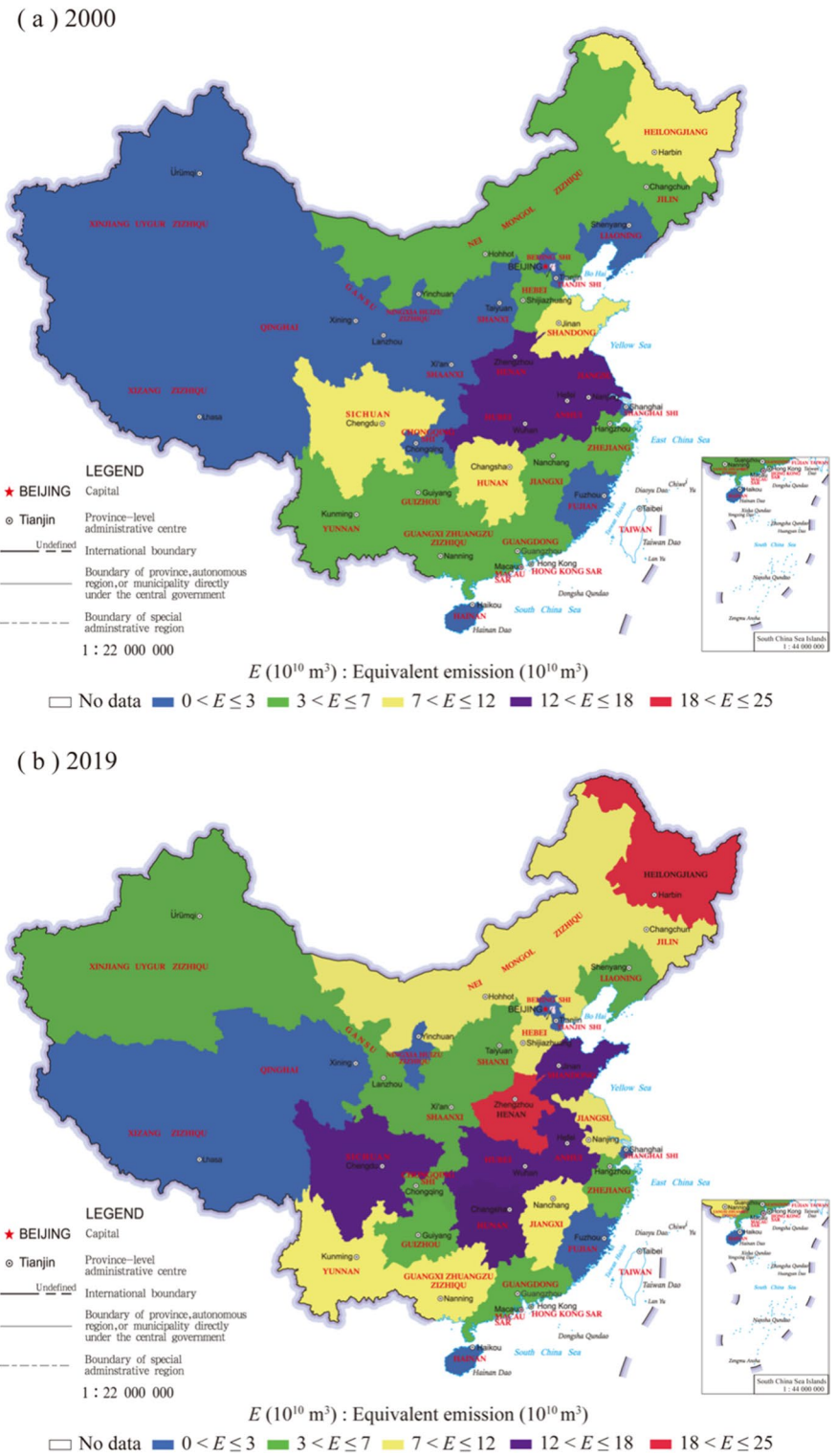
Among the above changes, the distribution changes of Heilongjiang, Henan, and Jiangsu deserve special attention. Compared the continuous changes of equal-standard discharges in the three regions from 2000 to 2019. It is not difficult to find that the pollution discharges of Heilongjiang Province have risen sharply, reaching  $24.35 \times 10^{10} \text{ m}^3$  in 2019. The upward trend of pollution discharges in Henan is slightly slower than that of Heilongjiang Province, but the growth rate is still faster, and the equal-standard discharges in 2019 are  $20.43 \times 10^{10} \text{ m}^3$ . Jiangsu shows a steady downward trend, and the equal-standard discharges have been reduced to  $11.39 \times 10^{10} \text{ m}^3$  in 2019 (Fig. 5). Heilongjiang and Henan fell back in 2007 and 2003 respectively, showing a rapid growth trend in the past 20 years, and became the highest pollution discharge area in 2019, which is closely related to the position of the two regions in China’s agricultural production. As a major planting province in China, it has made great contributions to solving China’s grain demand. Increasing production year by year must be accompanied by a large number of chemical fertilizer input and straw production, and it is inevitable that planting non-point source pollution will increase. After 2004, there was a continuous decline in equal-standard discharges in Jiangsu Province, but the downward trend was relatively smooth, and planting non-point source pollution was alleviated. Jiangsu is not only a big economic province but also a major agricultural province, and planting production accounts for a certain proportion. However, due to the economic development reform and planting structure adjustment, the discharges of planting non-point source pollution have been affected to a certain extent, and the pollution discharge in Jiangsu has decreased, but it is still at a medium pollution discharge level.

### Analysis on causes of planting non-point source pollution

By analyzing the status of pollution source and pollutants equal-standard discharge of planting non-point source



**Fig. 4** Distribution of equal-standard discharge of planting non-point source pollution in 2000 and 2019



pollution, it can be seen that China’s planting non-point source pollution has gradually increased in the past 20 years. In recent years, the extent of pollution in some areas has been decreased, which is caused by various reasons. Firstly, China’s rural economic development model is relatively extensive, and the demand for chemical fertilizers continues

to grow. Due to various soil conditions, low utilization rate of chemical fertilizer, insufficient development of planting technology, and high dependence of farmers on chemical fertilizer, the amount of chemical fertilizer application has been maintained at a high level. Secondly, with the input of agricultural products such as chemical fertilizers, the yield

of crop production has increased year after year, and the yield of straw has increased with it. However, there are still practical difficulties in straw recycling, the supervision of straw burning has been strengthened, and the accumulation of straw in cultivated land still accounts for a large proportion of straw treatment. Therefore, the problem of planting non-point source pollution caused by the accumulation of straw cannot be ignored. Thirdly, farmers accord with the characteristics of rational economic man. In the process of planting and production, farmers often take their own interests as the first consideration, ignoring the pollution caused by production behavior. This process is also one of the important reasons to aggravate planting non-point source pollution. However, with the aggravation of planting non-point source pollution, its prevention and control have been paid more attention and recognition, and the prevention and control of planting non-point source pollution has achieved initial success, which are closely related to the relevant subjects in the planting.

Planting non-point source pollution discharges in some regions shows a decreasing trend, which may be due to the following reasons. First of all, with the development of planting and the promotion of agricultural technology, farmers who serve as the main body of diversification, have improved their awareness of environmental protection. During the production process, some farmers will make behavioral decisions in combination with non-point source pollution problems, thus reducing the spread of planting non-point source pollution. Secondly, in order to ensure the sustainability of the planting production, the government has put forward relevant policies and measures to prevent and control agricultural non-point source pollution through the measures carried out by the green agriculture action, promotes the construction of the agricultural non-point source pollution control system and the modernization of capabilities, and promotes the formation of an agricultural non-point source pollution prevention and control mechanism that combines micro–macro policy linkage, policy innovation, and mechanism innovation. The prevention and control of China's planting non-point source pollution are still in a difficult exploration stage. How to balance the relationship between agricultural economic growth and planting non-point source pollution is an important issue to promote agricultural development and agricultural economic development. Therefore, this study will combine multiple factors to analyze its impact on planting non-point source pollution control, and strive to achieve the protection of agricultural economic growth and achieve planting non-point source pollution control to provide theoretical guidance.

### Spatial correlation analysis

In order to more accurately and intuitively judge the spatial correlation of planting non-point source pollution between

provinces, the geographical distance spatial adjacency matrix is used to calculate the global Moran index of planting non-point source pollution equal-standard discharges in the region from 2000 to 2019. The results are shown in Table 2.

From the results, it can be seen that the global Moran index of equal-standard discharges of planting non-point source pollution in the surveyed area from 2000 to 2019 is greater than 0,  $P$  value was less than 0.1, and  $Z$  value is greater than 1.65, indicating that inter-regional planting non-point source pollution discharges have significant positive spatial autocorrelation, that is, planting non-point source pollution discharges in each region are not isolated and randomly distributed. The amount of pollution discharged in a certain area can be affected by the environmental and economic factors in the adjacent area. Moran scatter plot identifies the relationship between an area and its neighbors by the location of the scatter points in four quadrants. The overall spatial interaction in the study area is dominated by two types: “H–H” (High–High aggregation type) and “L–L” (Low–Low aggregation type), “H–L” (High–Low aggregation type) and “L–H” (Low–High aggregation type) are auxiliary spatial pattern characteristics. Compared with the Moran scatter plot in 2000 and 2019, the number of regions in the “H–H” and “L–L” types in 2000 was 7 and 9 respectively, and the number of regions in the corresponding types changed to 8 and 11 respectively in 2019 (Fig. 6). The increase in the number of regions means that the spatial aggregation trend of “H–H” and “L–L” is on the rise, indicating that planting non-point source pollution discharges in some regions have increased or decreased significantly, and the spatial aggregation characteristics of regions are becoming more and more obvious. In 2000, the areas belonging to the “H–H” aggregation type were Henan, Jiangxi, Anhui, Jiangsu, Hubei, Hunan, and Guangdong; the areas belonging to “L–L” aggregation type include Beijing, Tianjin, Inner Mongolia, Guizhou, Tibet, Gansu, Qinghai, Ningxia, and Xinjiang. In 2019, the new areas that belong to the “H–H” aggregation type are Heilongjiang and Jilin, and the other regions are unchanged except Guangdong; the new areas belonging to the “L–L” aggregation type include Shanghai, Zhejiang, and Guangdong, with the exception of Inner Mongolia. According to the results, the regions with spatial aggregation characteristics are mainly concentrated in the major planting provinces and developed regions, which are more likely to produce spatial spillover effects. Therefore, attention should be paid to the spatial interaction characteristics of planting non-point source pollution discharges, and the impact of spatial factors on planting non-point source pollution prevention and related policies should be considered. How to make full use of the spatial interaction effect of pollution discharge to achieve planting non-point source pollution prevention and control, promote

agricultural economic growth, and promote the sustainable development of agricultural production environment is one of the important issues facing agricultural development at this stage.

## Regression analysis of spatial Dubin model

### Variable description statistics

Preprocess the panel data of 31 investigation areas from 2000 to 2019. The descriptive statistics of other variables were shown in Table 3 except geographical distance space adjacency weight matrix.

### Model applicability test

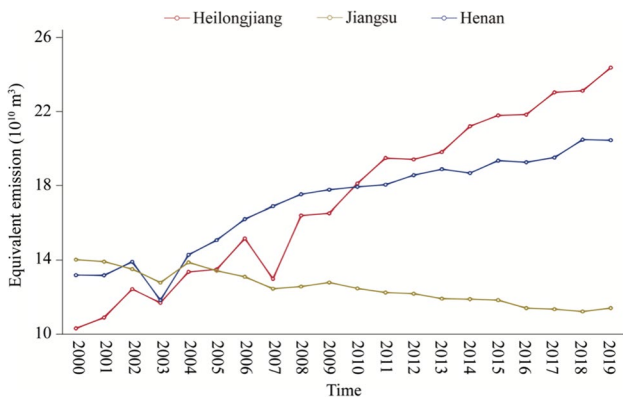
Carry out model applicability test on spatial panel data, and determine the applicable spatial measurement model of spatial panel data. First of all, through the LM test to determine whether the selected variables are suitable for spatial measurement model, if the test is passed, proceed to the next step of model selection. If the LM test is not passed, the selected variables should be followed up using a mixed OLS model. Secondly, according to the Hausman test, the fixed effects model or random effects model is selected for the spatial panel data. If the data pass the significance test, the original hypothesis is rejected and the fixed effects model is selected. On the contrary, the random effects model is adopted. Finally, if the fixed effects model is selected, the model robustness should be tested by LR test and Wald test. If the test results pass 1% significance test, it is shown that the fixed effects model will not degenerate into spatial error model (SEM) and spatial lag model (SLM). The results of the above process tests are shown in Table 4. Both LM and robust LMs pass the 1% significance test. The results show that the spatial panel data have obvious spatial correlation, and there are spatial error effect and spatial lag effect. The spatial econometric model can be introduced for subsequent analysis. Hausman test rejected the original hypothesis through 1% significance test and adopted fixed effects model. LR test passed 1% significance test. The results of SLM and SEM in Wald test passed 1% significance test. Therefore, this paper chooses the spatial Dubin model under the fixed effects for empirical analysis.

### SDM model regression analysis

Using Stata 15.0 software to realize the empirical analysis of the spatial econometric model of the impact of agricultural economic growth on planting non-point source pollution equal-standard discharges, estimate the model (10) by maximum likelihood method, and compare the  $R^2$  of SDM model under time fixed effect, space fixed effect, and double fixed

effect. Time fixed effect is better than spatial fixed effect and double fixed effect in the significance of explanatory variables and the goodness of fit of the model. From the perspective of economic significance, planting non-point source pollution discharge is more obviously affected by time, policy, and other changes than geographical factors. Therefore, it is considered that the time fixed effect is more in line with the research hypothesis of this paper. At the same time, in order to accurately reflect the spatial spillover effect of independent variables on dependent variables, the spillover effect of SDM model is decomposed into direct effect and indirect effect. The results of parameter estimation and spillover effect decomposition are shown in Table 5.

In the estimated result of SDM model, the value of the spatial lag coefficient  $\rho$  is  $-0.110$ ; passing the 5% significance test, it shows that there was a strong spatial autocorrelation between the equal-standard discharges of planting non-point source pollution in the study area, and the spatial spillover effect of the equal-standard discharges was significant, indicating that planting non-point source pollution discharges of a region can be affected by the proximity effect of the geographical location, ecological environment, and social and economic level of the adjacent areas. The estimated coefficients of  $\ln pGap$ ,  $\ln pce$ ,  $\ln ei$ ,  $\ln ms$ ,  $\ln pi$ , and  $\ln fs$  all passed the 1% significance test. Among them, the level of economic growth, the effective irrigation rate, and the level of financial support for agriculture are all negatively correlated with the equal-standard discharges of planting non-point source pollution, while the level of consumption capacity, the intensity of agricultural machinery input, and the level of risk perception are positively correlated with it. From the analysis of the impact of each factor on the region itself, the result of the agricultural economic growth coefficient is negative, indicating that the consumption of the agricultural environment in the region has reached an inflection point, and the agricultural economic growth is no longer completely dependent on the consumption of environmental resources. Through improving agricultural production technology, popularizing environment-friendly technology, and increasing agricultural financial support, the balanced development of agricultural economic growth and promoting the prevention and control of planting non-point source pollution can be achieved. At the same time, in recent years, various regions have introduced policies to benefit farmers, which have increased the income; and the consumption capacity of farmers and the level of agricultural modernization have been improved to a certain extent. The rational economic main characteristics of farmers will affect their decision-making behavior in the process of risk perception, which may lead to the problem of excessive planting non-point source pollution discharges. The estimated coefficients of  $W \times \ln pGap$ ,  $W \times \ln pce$ ,  $W \times \ln ei$ ,  $W \times \ln ms$ ,  $W \times \ln pi$ , and  $W \times \ln ap$  all passed the 10% significance test, indicating that the spatial effect between provinces



**Fig. 5** Variation trend of equal-standard discharge of planting non-point source pollution in Heilongjiang, Henan, and Jiangsu from 2000 to 2019

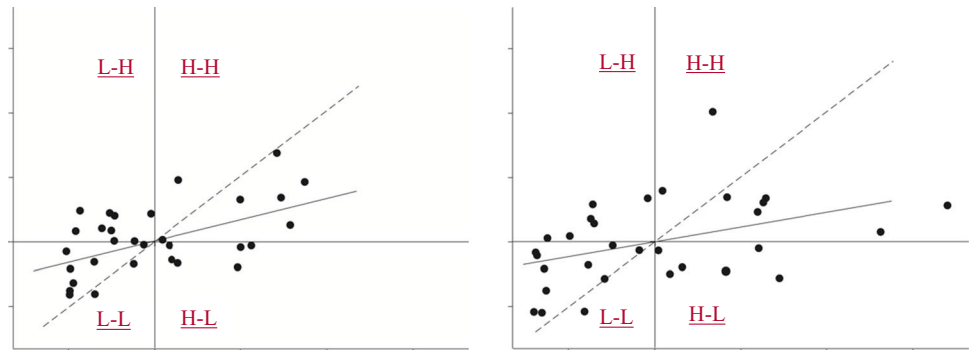
spillover effect is obvious. From the analysis of the influence of various factors on the regional, the influence direction of the economic growth level on the adjacent areas is different from the influence direction within the region, which indicates that the relationship between provincial agricultural economic growth is convergent growth, and there may be a competitive relationship between planting production in adjacent areas, which leads to the adjustment of planting structure in adjacent areas and the increase of non-point source pollution. Therefore, when formulating relevant policies in various regions, it is necessary not only to combine the local reality, but also to consider the influence of adjacent areas, and to fully pay attention to the spatial spillover effects of various factors on adjacent areas, so as to realize regional linkage planting non-point source pollution prevention and control.

The change direction of explanatory variable coeffi-

**Table 2** Global Moran’s *I* of 31 investigated regions from 2000 to 2019

Year	Moran’s <i>I</i>	<i>P</i> value	Z value	Year	Moran’s <i>I</i>	<i>P</i> value	Z value
2000	0.330	0.004	2.703	2010	0.251	0.017	2.119
2001	0.347	0.002	2.831	2011	0.258	0.015	2.169
2002	0.342	0.003	2.791	2012	0.260	0.015	2.183
2003	0.339	0.003	2.771	2013	0.267	0.013	2.237
2004	0.345	0.002	2.817	2014	0.256	0.015	2.157
2005	0.310	0.005	2.559	2015	0.258	0.015	2.172
2006	0.300	0.007	2.481	2016	0.259	0.015	2.178
2007	0.275	0.011	2.297	2017	0.255	0.016	2.145
2008	0.272	0.011	2.275	2018	0.215	0.032	1.849
2009	0.255	0.016	2.144	2019	0.227	0.026	1.940

**Fig. 6** Moran scatter diagram in 2000 and 2019. Note: *X* is the deviation of equal-standard pollution discharges of planting non-point source pollution in each region, *Y* is the spatial lag factor between each region and adjacent regions



is obvious. The level of economic growth, effective irrigation rate, and risk perception have a positive relationship with planting non-point source pollution discharges in the adjacent areas, while the level of consumption capacity, the intensity of agricultural machinery input, and the proportion of industrial structure are negatively correlated. The level of economic growth passed the test of significance level, indicating that the level of economic growth in this region has a positive correlation with the growth of planting non-point source pollution discharges in adjacent areas, and the positive spatial

effect in direct effect is consistent with that in time-fixed effect of SDM model, which indicates the influence degree of the influencing factors in a region to the equal-standard discharges of planting non-point source pollution. Indirect effect is the effect value of the cumulative spatial spillover effect between adjacent areas, which indicates the influence of local factors on planting non-point source pollution discharges in adjacent areas. The total effect reflects the change of planting non-point source pollution equal-standard



**Table 3** Description and statistics of panel data

Variable	Unit	Min	Max	Mean	Sta. dev
<i>P</i>	m <sup>3</sup> /hm <sup>2</sup>	3 852.67	24,488.04	11,754.79	3912.54
<i>pGap</i>	yuan	330.55	6504.72	1999.11	1135.37
<i>pce</i>	yuan	996.34	13,963.98	4250.30	2651.91
<i>ei</i>	%	0.139	1.234	0.429	0.194
<i>ms</i>	kW/hm <sup>2</sup>	1.32	26.98	5.90	3.51
<i>pi</i>	kg/hm <sup>2</sup>	1.42	59.94	11.14	8.93
<i>fs</i>	%	0.016	5.715	0.374	0.629
<i>di</i>	%	0	0.936	0.234	0.162
<i>ap</i>	%	0.003	0.281	0.108	0.059

**Table 4** Model applicability and model selection test results

Test		Statistical value	<i>P</i> value
LM-error	Moran's <i>I</i>	24.49	0.000 0
	LM	573.10	0.000 0
	Robust LM	24.91	0.000 0
LM-lag	LM	560.67	0.000 0
	Robust LM	12.48	0.000 0
Hausman		42.47	0.000 6
LR-SEM		47.61	0.000 0
LR-SLM		42.81	0.000 0
Wald-SEM		20.19	0.009 6
Wald-SLM		20.91	0.007 4

**Table 5** Estimation results of parameters and direct, indirect, and total effects

Variable	SDM-time	Direct effect	Indirect effect	Total effects
<i>lnpGap</i>	-0.163** (0.003)	-0.175*** (0.002)	0.397*** (0.000)	0.222** (0.017)
<i>lnpce</i>	0.365*** (0.000)	0.370*** (0.000)	-0.238** (0.047)	0.132 (0.332)
<i>lnei</i>	-0.115*** (0.002)	-0.128*** (0.001)	0.314*** (0.000)	0.186** (0.013)
<i>lnms</i>	0.124*** (0.000)	0.147*** (0.000)	-0.639*** (0.000)	-0.493*** (0.000)
<i>lnpi</i>	0.076*** (0.000)	0.069*** (0.000)	0.249*** (0.000)	0.318*** (0.000)
<i>lnfs</i>	-0.093*** (0.000)	-0.094*** (0.000)	0.039 (0.385)	-0.055 (0.240)
<i>ln di</i>	0.006 (0.610)	0.006 (0.630)	-0.000 (0.985)	0.005 (0.785)
<i>ln ap</i>	0.071 (0.107)	0.076 (0.104)	-0.169** (0.012)	-0.093 (0.222)
<i>W × lnpGap</i>	0.397*** (0.000)			
<i>W × lnpce</i>	-0.211* (0.089)			
<i>W × lnei</i>	0.320*** (0.000)			
<i>W × lnms</i>	-0.669*** (0.000)			
<i>W × lnpi</i>	0.275*** (0.000)			
<i>W × lnfs</i>	0.026 (0.570)			
<i>W × ln di</i>	-0.001 (0.972)			
<i>W × ln ap</i>	-0.171** (0.016)			
<i>rho</i>	-0.110** (0.026)			
<i>sigma2_e</i>	0.042** (0.000)			
<i>R</i> <sup>2</sup>	0.647			

\*\*\*, \*\*, and \* respectively indicate that the statistics are significant at the confidence level of 1%, 5%, and 10%, and the standard error is in parentheses

discharges in a region, and this change is influenced by the accumulation of self-driving factors and spatial spillover effects. In terms of direct effects, the direct effects of agricultural economic growth, effective irrigation rate, and financial support are all negative and significant at the 1% confidence level. The results showed that the increase of agricultural economic level, the improvement of effective irrigation rate, and financial support to agriculture could improve planting non-point source pollution discharges in this region. The direct effects of consumption capacity, input intensity of agricultural machinery, and risk perception level are positive, all significant at 1% confidence level, indicating that the increase of consumption capacity, input intensity of agricultural machinery, and risk perception would cause the increase of planting non-point source pollution discharges in this region. In terms of indirect effects, agricultural economic growth, consumption capacity, technological progress, risk perception, and industrial structure all pass the 5% significance level test, which shows that the influencing factors of this region have obvious spatial spillover effects on planting non-point sources pollution in adjacent areas. Among them, the direct effects of agricultural economic growth, effective irrigation rate, and risk perception are greater than the direct effect, and are all positive effects, indicating that the impact of the region on the adjacent areas of planting non-point source pollution discharges is obvious.

According to the results of the model, these are the following considerations for the influencing factors: (1) In the past 20 years, China has been mainly in the stage of consuming the agricultural environment to promote economic growth. Limited by the factors of natural conditions of cultivated land, the growth of agricultural economic will inevitably be accompanied by the increase of inputs such as chemical fertilizers. The increase of total crop production will also aggravate the solid waste discharge from farmland and increase the risk of planting non-point source pollution diffusion. However, with the development of modern agricultural technology and the policy of prevention and control of non-point source pollution, planting non-point source pollution has been controlled to a certain extent, but because of its relatively high cost, the treatment effect has not reached the best. Attention should be paid to the spatial spillover effect of agricultural economic level on planting non-point source pollutant discharges, especially the spillover effect between regions is greater than the direct effect within regions. (2) The improvement of farmers' consumption capacity can increase the local planting non-point source pollution discharges, but it has a negative spatial spillover effect on adjacent areas. The reason for this result may be the improvement of consumption capacity of rural residents leading to changes in consumption habits, the expansion of the demand for agricultural products, and the increase of the acceptance of new agricultural science and technology, which may lead to the increase of planting non-point source of pollution discharges. However, the change of environment-friendly technology in this region may cause learning effect in adjacent areas, and inhibit non-point source pollution discharges in adjacent areas to a certain extent, thus bringing negative spatial spillover effect. (3) The direct and indirect effects of the effective irrigation rate and the intensity of agricultural machinery use are opposite. It can be seen that different advanced technologies have different effects on planting non-point source pollution discharges. Pay attention to the dual nature of technological progress, explore the root causes of the different effects of technological progress on the region and adjacent areas, and choose appropriate advanced technology to effectively control planting non-point source pollution discharges. (4) The results of risk perception are consistent with the characteristics of farmers as a rational economic man. When farmers perceive the risk of agricultural production, then will take appropriate actions to increase chemical fertilizers and pesticides to ensure crop production. However, due to the different absorption rates of fertilizer by different crops and the differences of planting structure in different regions, planting non-point source pollution discharge may be aggravated, and there shows certain spatial clustering characteristics between regions. (5) Pay attention to the impact of financial support on planting non-point source pollution in the region, and

appropriate financial support for agriculture policy can help reduce planting non-point source pollution discharges. Fiscal policy has distinct regional pertinence and practicality, and the spatial spillover effect to neighboring regions is not obvious. Therefore, it is particularly important to propose fiscal policy according to the actual situation of the region. (6) Contrary to the role of fiscal policy, the change of industrial structure has obvious spillover effect on neighboring areas. If the proportion of agriculture in the local economy is lower, planting non-point source pollution in adjacent areas will be more serious. The low proportion of agriculture in the region indicates that the proportion of secondary and tertiary industries in the industrial structure of the region is relatively high, which is easy to attract the rural labor force transfer. At present, the shortage of land resources and the loss of surplus rural labor force are important problems in the current crop production. Under the condition of backward agricultural technology, it is easy to maintain agricultural production by increasing the amount of fertilizer and pesticide, which results in the increase of planting non-point source pollution in other areas.

## Conclusion and suggestions

The study analyzes the situation of China's planting non-point source pollution discharges from time and space dimensions. Under the condition of improving the object of agricultural non-point source pollution investigation and adding spatial factors and other control variables, the spatial Dubin model was used to analyze and test the impact of agricultural economic growth and other factors on planting non-point source pollution discharges. The research findings lead to the following conclusions. (1) From 2000 to 2019, China's planting non-point source pollution discharges have been increasing, and it is still in a relatively serious stage, and the areas with the highest pollution discharges at this stage are Heilongjiang and Henan. (2) During the past 20 years, planting non-point pollution discharges in 31 investigated areas showed obvious spatial aggregation characteristics, with positive spatial correlation, and showed a trend of pollution discharges diffusion. Planting non-point source pollution still needs to be paid close attention to. (3) According to the analysis of Dubin model results, economic growth, technological progress, financial support to agriculture, consumption capacity, risk perception, and industrial structure have significant spatial spillover effects on planting non-point source pollution discharges. (4) Different factors may have different effects on the local and adjacent areas in the effect decomposition, so it is necessary to pay attention to the guiding role of influential factors with large impact on planting non-point source pollution discharges.

Based on the above conclusions, the following suggestions are put forward. (1) Pay attention to the influencing factors that can inhibit planting non-point source pollution discharge in the region. All regions can develop a top-down complete management and supervision system by improving the government's financial support for agriculture and combining the production, discharge, prevention, and control of planting non-point source pollution, so as to ensure the steady growth of agricultural production and agricultural economy under the leading condition of effective prevention and control of planting non-point source pollution. (2) Actively utilize the significant spatial interaction among provinces. For example, exert the negative spatial spillover effects of consumption capacity, agricultural modernization level, and industrial structure. From the micro level, formulate incentive measures for farmers' behavior, and promulgate a complete agricultural production behavior regulation system. From the macro level, the industrial structure of the region should be regulated, so as to improve the utilization rate of resources and realize the effective prevention and control of planting non-point source pollution. (3) Strengthen education and training in rural areas, research, and promotion of science and technology in planting. Strengthen the education and training of rural residents on the characteristics of agricultural products and the awareness of planting non-point source pollution and attach great importance to scientific research and new technology promotion in planting, to provide support for the prevention and control of planting non-point source pollution.

**Author contribution** Xin Lin: conceptualization, data curation, methodology, software, formal analysis, writing—original draft, visualization. Jie Shang: writing—review and editing, supervision.

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**Data availability** Most of the data generated or analyzed in this study are included in this article. The remaining datasets used for analysis are available in the China Statistical Yearbook, China Rural Statistical Yearbook, Surface Water Environmental Quality Standard (GB3838-2002), and Handbook of calculation methods and coefficients for pollutant discharges from statistical survey of discharge sources.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

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