ECOLOGICAL SECURITY EVALUATION AND OBSTACLE DEGREE CHANGE OF CULTIVATED LAND UNDER THE INFLUENCE OF AGRICULTURAL NON-POINT SOURCE POLLUTION–BASED ON THE DATA OF 30 PROVINCES IN CHINA

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(Received 15th Jul 2022; accepted 14th Sep 2022)

Abstract. The macro data of 30 provinces (cities and districts) were selected in China from 2007 to 2019 to calculate the cultivated land ecological security index, and the index obstacle degree was analyzed. The results show that after the implementation of the reduction and efficiency increase policy, the ecological security level of the cultivated land was improved. However, the ecological security of cultivated land in Inner Mongolia, Qinghai and Xinjiang is still at a relatively unsafe level. From the perspective of each province, the intensity of fertilizer application in Henan and Heilongjiang is still the main obstacle factor. The application intensity of mulching film in Anhui, Hunan, Jiangsu, Jiangxi, Liaoning, Sichuan, Fujian, Hainan, Zhejiang, Gansu, Guizhou and Qinghai is the main obstacle factor. China's policy of reducing and increasing efficiency has had some effect, but the pollution problem still exists. Therefore, it is necessary to focus on farmers' planting behavior and encourage farmers to choose green production behavior through reward and punishment measures and educational means.
Keywords: *cultivated land security, reduction and efficiency, PSR model, obstacle factors, regional differences*

Introduction

In 2015, the "No. 1 central document" pointed out that we should vigorously control agricultural non-point source pollution through "strengthening agricultural ecological management". In the same year, the Ministry of Agriculture issued the "Implementation Opinions on the fight against agricultural non-point source pollution", which also showed the government's determination to control agricultural non-point source pollution. Fertilizer, pesticide, plastic film and other agricultural production factors have provided strong support for China's agricultural production. By 2020, China's total grain output reached 669.5 million tons, realizing 17 consecutive increases in grain output, which was a record high. Chemical fertilizers, pesticides and plastic films have made great contributions to grain production. However, due to the extensive agricultural production mode and the unreasonable use of a large number of chemical production factors, such as chemical fertilizer, pesticide and plastic film, the serious non-point source pollution and the increasingly poor ecological environment are important reasons for the government to issue policies to control non-point source pollution. Agricultural non-point source pollution has also seriously affected cultivated land. Cultivated land is not only the most basic means of production for agricultural production, but also an important non-renewable resource to support human survival. Cultivated land ecosystems should not only maintain its normal function, but also provide assistance for

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

social and economic development (Zhao et al., 2018; Gao et al., 2021). Cultivated land security is directly related to food security and social security. China is a country with a large population and is facing great pressure on its food security. China's per capita cultivated land area is very small. To ensure that the limited cultivated land can stably and effectively produce high-quality grain, on the one hand, we should adhere to the red line of 120 million hm^2 of cultivated land, and on the other hand, we should ensure the ecological security of cultivated land. Therefore, under the full consideration of the negative impact of agricultural non-point source pollution, we should effectively evaluate the ecological security of cultivated land and pay attention to the great pressure faced by cultivated land resources, which is of great significance to protecting China's cultivated land resources, stabilize and improve China's grain output and quality, and promote the green and sustainable development of agriculture.

Research on cultivated land security began many years ago, mainly discussing land security, including land sustainability and land carrying capacity. Relevant scholars pointed out that the need to coordinate food production, ecosystem services and biodiversity protection has prompted people to seek more sustainable land production methods (Renard et al., 2012). Population growth, changes in human dietary structure, and rising consumption levels will drive the environmental footprint of land use to increase further and affect the sustainability of land (Vuuren et al., 2005). People's current use of resources, land planning, and life and production methods are all unsustainable, and systemic flaws need to be resolved to avoid excessive carrying capacity (Lane, 2010). Some scholars have analyzed the carrying capacity of land resources under the continuous and improved management system based on the demand and supply of total digestible nutrients (TDN) in the study area (Thapa, 2000). From the conceptual definition of cultivated land ecological security, the academic community has not reached a consensus on the interpretation of the connotation of cultivated land ecological security, but all members emphasize the stability of cultivated land system, environmental security and ensuring the sustainable development of the social economy (Zhang et al., 2012; Zhu et al., 2007; Cai et al., 2004). The application of ecological security assessment methods for cultivated land is relatively mature, including the PSR model (Yuan et al., 2019; Han et al., 2009), DPSIR model (Mailikai et al., 2019), state space model (Zheng et al., 2020), the GA-BP neural network model (Wu et al., 2019), and the quantum genetic projection pursuit model (Nie et al., 2015). Some scholars also predict the future ecological security of cultivated land by measuring the ecological evaluation value of cultivated land in a certain year on the basis of existing data (Ma et al., 2018; Fan et al., 2016). Some scholars analyze the obstacles to the ecological security of cultivated land (Zhao et al., 2018, 2014). From the perspective of influencing factors, although the factors affecting the ecological security of cultivated land are different at different stages, population, arable land area, chemical fertilizer load per arable land, pesticide load per arable land, mulching film application intensity, soil erosion, etc., are the main restrictive factors for the ecological security of cultivated land (Han et al., 2009; Mailikai et al., 2019; Fan et al., 2016; Zheng et al., 2015). From the perspective of the scope of research, most scholars conduct overall farmland ecological security assessments in a small area. Luo et al. (2019) constructed a farmland ecological footprint model to empirically measure the farmland ecological footprint and ecological carrying capacity for food security in 13 provinces (regions) in the main grain production area. Wang et al. (2021) conducted a comprehensive evaluation of the safety of arable land resource utilization in Hunan Province. Li et al. (2018) made a

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dynamic prediction of the ecological security of cultivated land in Sichuan. Wen et al. (2021) studied the ecological security of cultivated land in the Dongting Lake Plain and found its obstacles. Zhang et al. (2013) evaluated the ecological security of cultivated land across the country and analyzed its obstacles. Although many scholars have included agricultural non-point source pollution indicators in the evaluation system when evaluating cultivated land ecological security, they have not elaborated them in detail. The concept of "agricultural non-point source pollution" originated from the definition of the clean water act of the United States in 1979: agricultural non-point source pollution is water pollution formed by pesticides, nitrogen and other pollutants through surface runoff or groundwater through uncontrollable, dispersed and vast areas in agricultural production activities (Cheng et al., 2018). Agricultural non-point source pollution refers to the pollution of water layers, lakes, riverbanks, shores, atmospheres and other ecosystems caused by the improper use of chemical fertilizers, pesticides, agricultural film, feed and other chemicals in the process of agricultural production, as well as the improper treatment of livestock manure, crop straw and farmers' domestic waste in production (Luo et al., 2015). Agricultural non-point source pollution is closely related to agricultural activities. Such agricultural activities mainly include the excessive or improper application of agricultural chemicals, such as chemical fertilizers and pesticides, stocking and free-range livestock and poultry, fishery breeding, and unreasonable farmland irrigation, especially sewage irrigation (Deng et al., 2018). In this study, agricultural non-point source pollution refers to the pollution caused by the excessive use of chemical fertilizer, pesticide and plastic film.

Through the collation of the relevant literature, it can be found that there are rich research contents related to cultivated land ecological security evaluation. In the cultivated land ecological security evaluation system, scholars also include the application intensity of chemical fertilizer, pesticide and plastic film in the evaluation system, but there is still insufficient research. On the one hand, there is a lack of large-scale ecological security evaluation of cultivated land and zoning comparison according to certain standards. Few scholars have conducted research, especially in the period of rising global food pressure, analyzing the ecological status of cultivated land in different food functional areas in China according to the positioning and division of food functional areas will be conducive to the formulation and implementation of cultivated land protection policies and the stabilization of food security; on the other hand, from the perspective of the time dimension, China officially began to control agricultural non-point source pollution in 2015. It is necessary to take 2015 as the time node, fully analyze the changes in cultivated land ecological security index before and after 2015, and clarify whether agricultural non-point source pollution has been controlled. Based on this, the aims of this paper were to select 30 provinces and cities in China, focus on the safety evaluation of cultivated land from the perspective of agricultural non-point source pollution, and analyze the obstacle degree. According to the standards of the State Food Administration and the Ministry of finance, considering the differences in agricultural development in different provinces and cities, 30 provinces and cities are classified, evaluated and compared. Especially since the government promoted the action of reduction and efficiency increase in 2015, the authors investigate whether the contribution of agricultural non-point source pollution to cultivated land security has changed, whether it is still an important factor affecting cultivated land ecological security, and the policy effects in different regions and regions. Through the above analysis, this paper investigates whether the agricultural non-point source pollution

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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control has achieved phased results, and discusses how the government should control agricultural non-point source pollution in the next step to ensure the ecological security of cultivated land. The main novel aspects of this study are as follows: (1) this paper uses the improved entropy method to add time variables to process the data as a whole. (2) This paper focuses on the changes in cultivated land ecological security and obstacle degree before and after the implementation of the reduction and efficiency increase policy in 2015. (3) This paper selects 30 provinces and urban areas in China, and divides them according to their functions, so as to enhance the pertinence.

Materials and methods

Research methods

The improved entropy method: This comprehensive evaluation research, according to the need to determine the weight, was divided into a subjective evaluation method and an objective evaluation method. This article mainly used the entropy method as the objective evaluation method to accurately and objectively evaluate the object. In order to realize the comparison between different regions in different years, this paper improved the traditional entropy method and added time variables to ensure that the empirical analysis results fit the needs of the investigation. The steps to improve the entropy method are as follows:

Standardization of indicators:

Positive index: $$\beta_{\alpha\, ij} = \frac{x_{\alpha\, ij} - \min(x_{\alpha\, ij})}{\max(x_{\alpha\, ij}) - \min(x_{\alpha\, ij})} \quad \text{(Eq.1)}$$

Negative index: $$\beta_{\alpha\, ij} = \frac{\max(x_{\alpha\, ij}) - x_{\alpha\, ij}}{\max(x_{\alpha\, ij}) - \min(x_{\alpha\, ij})} \quad \text{(Eq.2)}$$

The weight of each indicator feature: $$\beta'_{\alpha\, ij} = \frac{\beta_{\alpha\, ij}}{\sum_{\alpha}\sum_{i}\beta_{\alpha\, ij}} \quad \text{(Eq.3)}$$

Calculating the information entropy of the indicator:

$$E_j = -k\sum_{\alpha}\sum_{i}\beta'_{ij}\ln(\beta_{\alpha\, ij})\ \ k = \ln(yt), k \succ 0 \quad \text{(Eq.4)}$$

Calculating the redundancy of indicators:

$$F_j = 1 - E_j \quad \text{(Eq.5)}$$

Calculating the weight of each indicator:

$$W_j = \frac{F_j}{\sum_{j} F_j} \quad \text{(Eq.6)}$$

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Cultivated land ecological security evaluation index:

$$Z_{\alpha i} = \sum_{j} (W_j * \beta_{\alpha ij}) \quad \text{(Eq.7)}$$

Obstacle evaluation method: There are multiple evaluation indicators in different dimensions. Each evaluation index has a different degree of impact on the ecological security of cultivated land. This paper used the obstacle degree model to determine the key factors hindering the ecological security of cultivated land. The model is as follows:

$$Q_j = \frac{(1-\beta_{\alpha ij})*(W_j * V_e)}{\sum_{j=1}(1-\beta_{\alpha ij})*(W_j * V_e)} * 100\% \quad \text{(Eq.8)}$$

Data source and processing

The data comes from the "China Statistical Yearbook", "China Rural Statistical Yearbook", "China Environmental Statistical Yearbook", "China Education Statistical Yearbook", statistical yearbooks of various provinces and cities, and relevant government website data. Each Yearbook is published on the Chinese Internet platform. The obstacle degree was calculated using three indicators in the pressure subsystem, state subsystem and response subsystem of the cultivated land ecological security evaluation. Grain production is one of the most important functions of cultivated land. At present, the global food pressure is increasing. In addition to reducing food loss, it is also necessary to ensure the stable production and supply of food. Therefore, it is necessary to divide regions according to the functional orientation of grain production, explore the ecological status of cultivated land in different regions, identify obstacles, improve the ecological security coefficient of cultivated land, and ensure grain quality and yield. According to research needs, 30 provinces (except for Hong Kong, Macau, and Taiwan, due to the serious lack of data on some indicators in Tibet, so they are not included in the scope of the study) were divided into three main grain-producing areas, main grain sales areas and grain balance areas. The main grain-producing areas refer to the areas with grain production advantages in natural and social conditions and those that are suitable for planting grain crops, including 13 provinces, namely, Hebei, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan and Sichuan; The main grain sales areas refer to the grain consumption areas with a small land areas, large population and low grain output, including the 7 provinces of Guangdong, Shanghai, Fujian, Zhejiang, Hainan, Beijing and Tianjin. Grain balance areas refer to the areas where grain output can basically achieve self-sufficiency, including the 10 provinces of Guangxi, Yunnan, Chongqing, Qinghai, Ningxia, Shanxi, Shǎnxi, Gansu, Guizhou and Xinjiang. For some missing data, the mean method was used to supplement them before the evaluation. We used the extreme value method to standardize all indicator data. The calculation and sorting of relevant data were performed using Excel.

Determination of research scope

The research period of this study was from 2007 to 2019. Since some data of 2020 have not been officially released, such as the number of rural cultural and technical

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training schools, the end of the study was 2019. In this study, when analyzing the overall level of arable land ecological security in various functional areas and provinces (cities and districts), due to the large amount of data, we selected 2007, 2011, 2015 and 2019 for the comparison. When analyzing the barrier degree of cultivated land ecological security in each functional area and each province (city and district), we chose 2007, 2015 and 2019 for the comparison.

Cultivated land ecological security evaluation system

The PSR model is proposed by the United Nations Environment Programme and the Organization for Economic Cooperation and Development to evaluate the global environmental and ecological conditions. Due to its comprehensiveness and flexibility, it is widely used in the evaluation of ecological security and resource utilization (Cui et al., 2021). In the field of cultivated land research, many scholars also use the PSR model to analyze the ecological security of cultivated land (Liu et al., 2017, 2019; Pan et al., 2016). This paper established the PSR model to evaluate the ecological security of cultivated land from three aspects: the pressure subsystem, the state subsystem and the response subsystem. *Table 1* shows the specific contents of the cultivated land ecological security evaluation index system under the influence of agricultural non-point source pollution.

"Pressure" (P) refers to the impact of human agricultural production behavior on the cultivated land ecosystem. Fertilizer application intensity, pesticide application intensity and plastic film application intensity were mainly selected, which mainly reflects the impact of various agricultural production factors on cultivated land ecology in agricultural production and operation activities. The use of a large number of chemical fertilizers, pesticides and plastic film will cause a large loss of soil nutrients and damage the soil structure, and the residual pollutants will diffuse with rainwater scouring, surface runoff and infiltration. This will have a widespread negative impact.

Figure 1 shows the changes in fertilizer, plastic film and pesticide use in functional areas. We can see that the use of chemical fertilizers and pesticides increased first and then decreased. The time point of decline was approximately 2015. This is closely related to China's policy of reducing emissions and increasing efficiency. However, the use of plastic film still showed an upward trend. Whether this will affect the ecological security of arable land is worth discussing. Of course, although the use of chemical fertilizers and pesticides has decreased, it does not mean that it will not have a negative impact on the cultivated land, which requires the specific analysis of certain problems.

"State" (S) refers to the natural state and production state of the cultivated land ecosystem. Due to the lack of official statistical data on the geographic nature of farming, this study mainly used farmland production status data. Water and soil cooperative regulation (ratio of effective irrigation area to cultivated land area) mainly reflects whether cultivated land is effectively irrigated (effective irrigation refers to the cultivated land with complete supporting facilities and can be irrigated normally during the planting period) and the utilization degree of water resources. The reclamation rate (ratio of cultivated land area to total land area) and multiple cropping index (ratio of crop sowing area to cultivated land area) refer to the average number of crops planted on the same plot of arable land in one year; this indicator represents the degree of utilization of cultivated land. Grain yield per unit area (ratio of total grain yield to grain crop area) mainly reflects the degree of grain supply.

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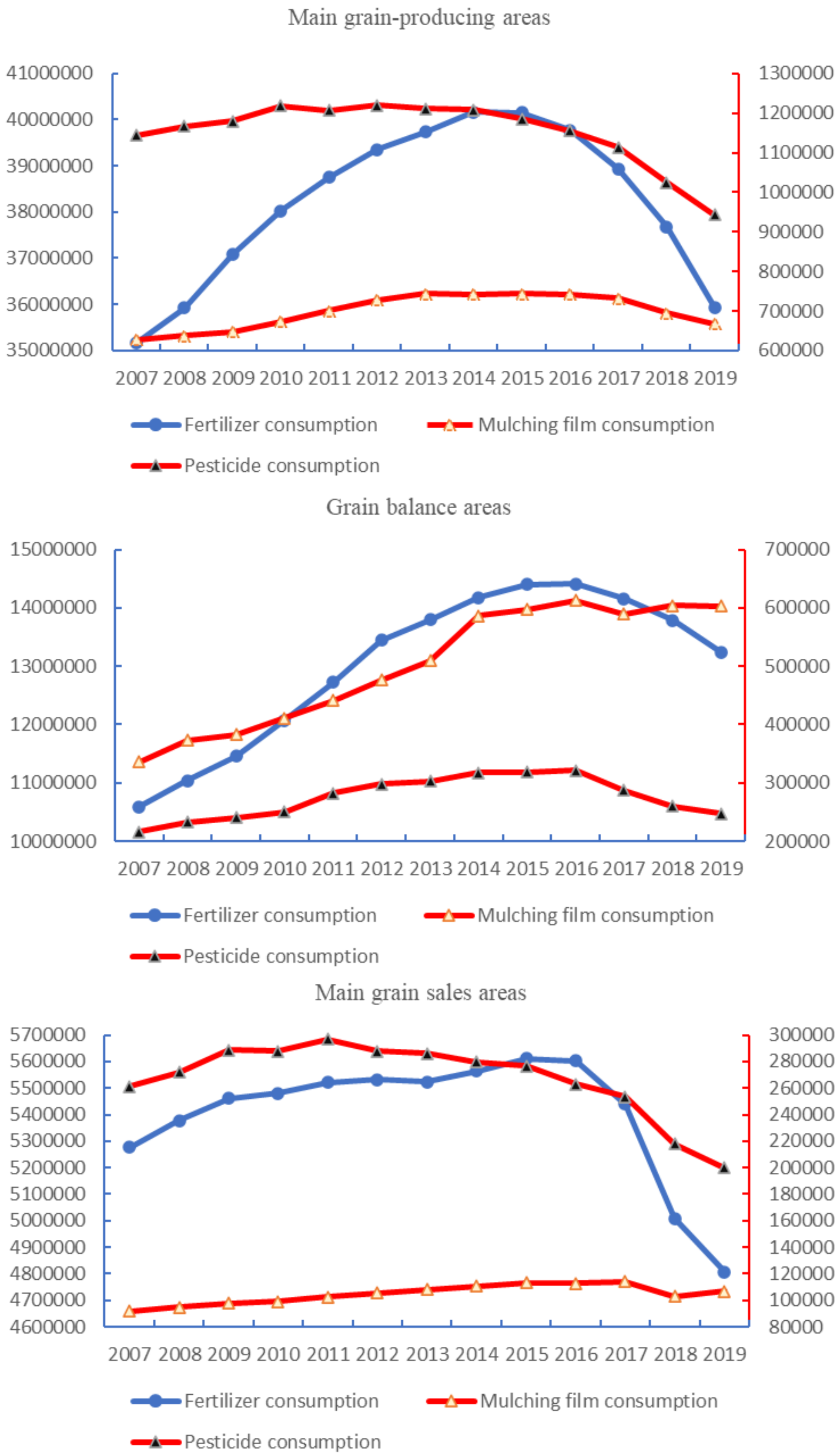

Figure 1. *Changes in the use of chemical fertilizers, plastic films and pesticides in functional areas from 2007 to 2019*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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"Response" (R) refers to the measures taken by humankind to face the problems in the cultivated land ecosystem. Forest coverage mainly reflects the degree of environmental protection. The per capita net income of farmers mainly reflects the economic income of farmers, and the level of farmers' income will affect farmers' production input in the next year. The number of rural cultural and technical training schools mainly reflects the regional vocational training situation. The proportion of farmers' agricultural fixed asset investment, the proportion of intermediate consumption in agricultural production, the proportion of water-saving irrigation (the ratio of water-saving irrigation area to cultivated land irrigation area) and the mechanization level (the ratio of total power of agricultural machinery to cultivated land area) mainly reflect the level of agricultural production conditions.

Table 1. *Evaluation index system of cultivated land ecological security under the influence of agricultural non-point source pollution*

Target layer	Criterion layer	Index layer	Index nature	Index weight
Ecological security assessment of cultivated land under the influence of agricultural non-point source pollution	Pressure (0.234)	Fertilizer application intensity (P1)	-	0.072
		Pesticide application intensity (P2)	-	0.085
		Intensity of mulching film application (P3)	-	0077
	State (0.284)	Water-soil coordination (S1)	+	0.071
		Reclamation rate (S2)	+	0.070
		Multiple crop index (S3)	-	0.063
		Grain production per unit area (S4)	-	0.080
	Response (0.483)	Forest cover rate (R1)	+	0.013
		Per capita net income of farmers (R2)	+	0.001
		Number of rural cultural and technical training schools (R3)	+	0.192
		Proportion of farmers' agricultural investment in fixed assets (R4)	+	0.087
		Proportion of agricultural production intermediate consumption (R5)	-	0.073
		Proportion of water-saving irrigation (R6)	+	0062
		Mechanization level (R7)	+	0.055

Cultivated land ecological security evaluation and spatial heterogeneity analysis

Since the calculated value of the comprehensive evaluation value of cultivated land ecological security is between 0 and 1, according to the relevant literature research, combined with the research practice of this paper and the limitations of index selection, the comprehensive evaluation of cultivated land ecological security was divided into five levels. Z represents the comprehensive evaluation index of cultivated land ecological security. The greater the Z value, the higher the cultivated land ecological security. The smaller the Z value, the lower the ecological security of cultivated land. Level I ($Z \leq 0.35$) denotes unsafe; level II ($0.35 < Z \leq 0.45$) denotes relatively unsafe; level III ($0.45 < Z \leq 0.55$) denotes critical safety; level IV ($0.55 < Z \leq 0.65$) denotes relatively safer; and level V ($Z > 0.65$) denotes safe.

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Overall evaluation of cultivated land ecological security in functional areas

Figure 2 shows the cultivated land ecological security index in different grain functional areas. The ecological security level of cultivated land changed in the main grain-producing areas, grain balance areas and main grain sales areas from 2007 to 2019. The ecological security of cultivated land in the three regions remained basically unchanged from 2007 to 2015, and was at a relatively unsafe level. From 2015 to 2019, the ecological security of cultivated land in the three regions significantly improved. The main grain production areas and grain balance areas were at a relatively safe level, and the main grain sales areas were at a critical safety level. From the perspective of the contribution of each subsystem, the pressure subsystem in the main grain production area declined from 2007 to 2015, and it improved significantly from 2015 to 2019. The state subsystem increased slightly, and the response subsystem increased by 0.1834. The pressure subsystem in the grain balance area from 2007 to 2015. The magnitude of the decrease was 0.1518. The contribution rate from 2015 to 2019 rebounded but was still lower than the initial stage of the research interval. The status subsystem fluctuated and changed, the response subsystem increased greatly, and contributed the most to the ecological security of cultivated land. The main grain sales areas were the pressure component. The system declined from 2007 to 2015 and increased from 2015 to 2019. The contribution of the state subsystem gradually decreased, and the contribution of the response subsystem rose steadily.

Figure 3 shows the visualization of cultivated land ecological security in various provinces of China using ArcGIS software. The map number of China is GS (2022) 1873. We can see that the changes of cultivated land ecological security in various provinces are fluctuating. In fact, in 2015, the government began to implement the policy of reducing and increasing efficiency. In that year, most of the cultivated land ecological security in various provinces was at the unsafe level. By 2019, only Inner Mongolia, Qinghai and Xinjiang were at the relatively unsafe level. This shows that the policy of reducing and increasing efficiency really plays an important role in improving the ecological security of arable land.

Evaluation of cultivated land ecological security in main grain-producing areas

Table 2 shows the calculation results of cultivated land ecological security level in main grain-producing areas from 2007 to 2019. It can be seen that the comprehensive indexes of Anhui and Jiangsu did not change from 2007 to 2015, and were at a relatively unsafe and unsafe level, respectively. The comprehensive indexes of Hebei, Hubei and Shandong gradually increased; the comprehensive indexes of Henan, Jiangxi and Inner Mongolia decreased; and the comprehensive indexes of Heilongjiang, Hunan and Liaoning increased. Although the comprehensive indexes of Jilin and Sichuan changed in this study range, the ecological security level of cultivated land remained at the original level in 2015. From 2015 to 2019, the comprehensive index of other provinces, except the main grain-producing areas, increased, but the evaluation level of cultivated land ecological security in Liaoning remained unchanged. Among them, Anhui, Henan, Hubei and Sichuan were at the safety level, Hebei, Heilongjiang, Hunan, Jiangsu, Jiangxi and Shandong were at the relatively safe level; Jilin and Liaoning were at the critical safety level; and Inner Mongolia was at the relatively unsafe level. From the perspective of the pressure subsystem, the pressure subsystems of Anhui, Hebei, Henan, Heilongjiang, Hunan, Jilin, Jiangxi, Liaoning, Inner Mongolia, Shandong and Sichuan showed fluctuations and decreases from 2007 to 2015, the pressure indexes of

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Hubei and Jiangsu continued to rise, and the pressure indexes of all provinces increased from 2015 to 2019. From the perspective of status subsystem, in the period 2007-2015, except for the in Hebei, Jiangsu and Shandong, the fluctuation in the status index in other provinces increased. From 2015 to 2019, the status index in Henan, Heilongjiang, Jilin, Liaoning and Inner Mongolia decreased, and the status index in other provinces increased. From the perspective of the response subsystem, the response index of Heilongjiang, Jiangxi and Sichuan decreased from 2007 to 2015; the response index of other provinces increased; the response index of Hebei, Liaoning and Shandong decreased; and the response index of other provinces increased from 2015 to 2019.

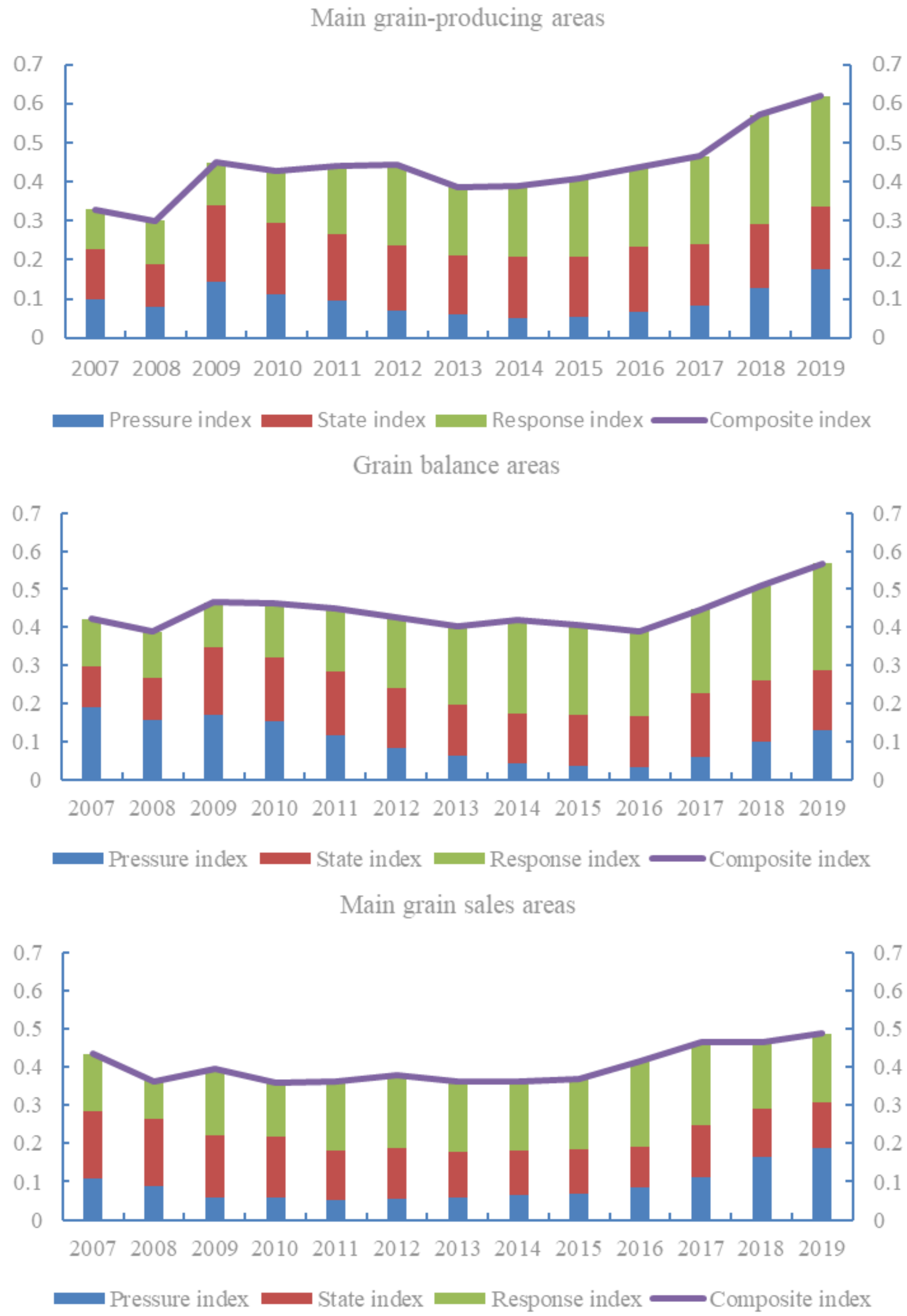

Figure 2. *Ecological security assessment of cultivated land in functional areas from 2007 to 2019*

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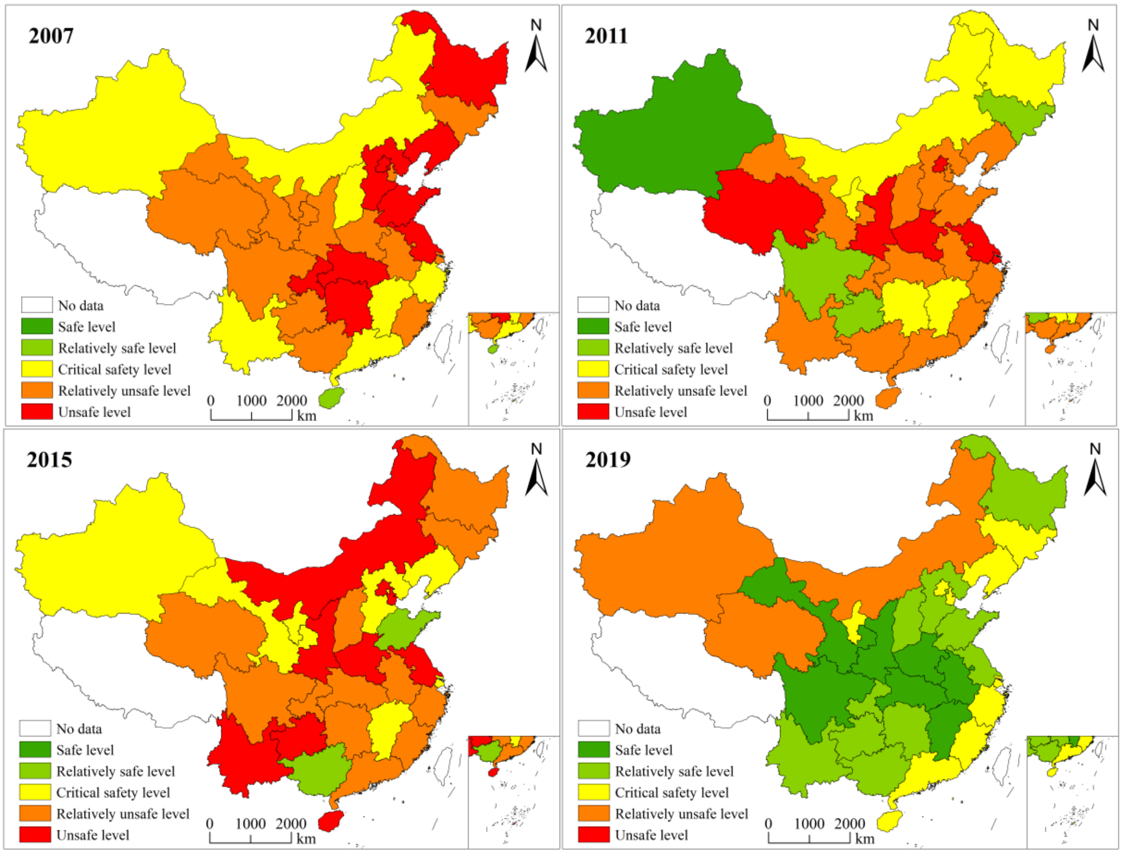

Figure 3. *Spatial variation of cultivated land ecological security in China's provinces from 2007 to 2019*

Table 2. *Evaluation of cultivated land ecological security in main grain-producing areas from 2007 to 2019*

Areas	Indexes	2007	2011	2015	2019
Anhui	Pressure index	0.1708	0.0692	0.0370	0.1571
	State index	0.0852	0.1489	0.1724	0.1959
	Response index	0.1050	0.1788	0.1632	0.4035
	Composite index	0.3610 (II)	0.3969 (II)	0.3726 (II)	0.7564 (V)
Hebei	Pressure index	0.0431	0.0466	0.0225	0.2336
	State index	0.1393	0.1776	0.1317	0.1646
	Response index	0.0519	0.1807	0.3574	0.1824
	Composite index	0.2342 (I)	0.4049 (II)	0.5117 (III)	0.5806 (IV)
Henan	Pressure index	0.1824	0.0490	0.0127	0.1629
	State index	0.1246	0.2151	0.1640	0.1279
	Response index	0.0619	0.0696	0.1254	0.4147
	Composite index	0.3688 (II)	0.3337 (I)	0.3021 (I)	0.7055 (V)
Heilongjiang	Pressure index	0.0498	0.1367	0.0697	0.2023
	State index	0.0820	0.1868	0.2009	0.1731
	Response index	0.1453	0.1673	0.1285	0.1920
	Composite index	0.2770 (I)	0.4908 (III)	0.3991 (II)	0.5673 (IV)

Hubei	Pressure index	0.0518	0.0555	0.0788	0.2336
	State index	0.0973	0.1377	0.1528	0.1859
	Response index	0.1010	0.2152	0.1580	0.4238
	Composite index	0.2501 (I)	0.4084 (II)	0.3896 (II)	0.8433 (V)
Hunan	Pressure index	0.0925	0.1141	0.0284	0.1748
	State index	0.1715	0.1657	0.1846	0.2135
	Response index	0.0777	0.2020	0.1918	0.2032
	Composite index	0.3416 (I)	0.4818 (III)	0.4048 (II)	0.5914 (IV)
Jilin	Pressure index	0.1645	0.1506	0.0267	0.0827
	State index	0.1326	0.1926	0.1538	0.1499
	Response index	0.0989	0.2975	0.2007	0.2244
	Composite index	0.3960 (II)	0.6407 (IV)	0.3812 (II)	0.4571 (III)
Jiangsu	Pressure index	0.0341	0.0567	0.0818	0.1753
	State index	0.2149	0.0852	0.0620	0.1098
	Response index	0.0232	0.1070	0.1978	0.3060
	Composite index	0.2722 (I)	0.2488 (I)	0.3416 (I)	0.5910 (IV)
Jiangxi	Pressure index	0.0960	0.0812	0.0356	0.1721
	State index	0.1358	0.1706	0.1888	0.1925
	Response index	0.2328	0.2023	0.2299	0.2902
	Composite index	0.4646 (III)	0.4540 (II)	0.4543 (II)	0.6549 (IV)
Liaoning	Pressure index	0.0767	0.1298	0.0711	0.1633
	State index	0.1091	0.1659	0.1526	0.1411
	Response index	0.0973	0.0980	0.2354	0.1957
	Composite index	0.2831 (I)	0.3937 (II)	0.4591 (III)	0.5001 (III)
Inner Mongolia	Pressure index	0.2218	0.1992	0.0435	0.0735
	State index	0.1366	0.1884	0.1510	0.0967
	Response index	0.1044	0.1361	0.1156	0.2250
	Composite index	0.4627 (III)	0.5237 (III)	0.3100 (I)	0.3953 (II)
Shangdong	Pressure index	0.0119	0.0638	0.1110	0.2336
	State index	0.1341	0.1844	0.1176	0.1389
	Response index	0.0204	0.1475	0.3219	0.2712
	Composite index	0.1664 (I)	0.3957 (II)	0.5504 (III)	0.6437 (IV)
Sichuan	Pressure index	0.0798	0.0940	0.0736	0.2072
	State index	0.1251	0.1903	0.1879	0.2066
	Response index	0.1874	0.2761	0.1553	0.3587
	Composite index	0.3923 (II)	0.5604 (IV)	0.4169 (II)	0.7724 (V)

Ecological security evaluation of cultivated land in main grain sales areas

Table 3 shows the calculation results of the cultivated land ecological security level in main grain sales areas from 2007 to 2019. It can be seen that the comprehensive indexes of Beijing, Fujian and Guangdong did not change from 2007 to 2015. Among them, Beijing was at an unsafe level, Fujian and Guangdong were at a relatively unsafe level, the comprehensive indexes of Hainan and Zhejiang decreased, the comprehensive index of Shanghai continued to rise, and the comprehensive index of Tianjin decreased.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

From 2015 to 2019, the provincial (city and district) comprehensive index of the main grain sales areas increased, but the evaluation level of cultivated land ecological security in Shanghai remained unchanged, and all provinces (city and district) were at the critical safety level. From the perspective of the pressure subsystem, from 2007 to 2015, except that the pressure index of Hebei and Guangdong increased to some extent in 2011, all provinces (cities and districts) showed a decline in 2015, and the pressure index of all provinces (cities and districts) increased from 2015 to 2019. From the perspective of the status subsystem, the status indexes of Beijing, Guangdong, Tianjin and Zhejiang continued to decline from 2007 to 2015, while the status indexes of Fujian, Hainan and Shanghai decreased. From 2015 to 2019, the status indexes of other provinces (cities and districts) increased, except Beijing and Zhejiang. Regarding the response subsystem, from 2007 to 2015, the response indexes of Fujian, Guangdong and Shanghai continued to rise, while the response indexes of other provinces decreased. From 2015 to 2019, the response indexes of Beijing, Hainan and Tianjin increased, and the response indexes of other provinces decreased.

Table 3. *Evaluation of cultivated land ecological security in main grain sales areas from 2007 to 2019*

Areas	Indexes	2007	2011	2015	2019
Beijing	Pressure index	0.0239	0.0336	0.1266	0.2336
	State index	0.1763	0.1167	0.0988	0.0796
	Response index	0.1312	0.1454	0.0947	0.1505
	Composite index	0.3315 (I)	0.2957 (I)	0.3201 (I)	0.4637 (III)
Fujian	Pressure index	0.0996	0.0629	0.0285	0.1666
	State index	0.0942	0.1021	0.1237	0.1676
	Response index	0.1668	0.1937	0.2749	0.1489
	Composite index	0.3607 (II)	0.3587 (II)	0.4271 (II)	0.4831 (III)
Guangdong	Pressure index	0.2238	0.0548	0.0158	0.1458
	State index	0.1957	0.1350	0.1062	0.1155
	Response index	0.0308	0.2077	0.2515	0.2143
	Composite index	0.4504 (II)	0.3975 (II)	0.3735 (II)	0.4756 (III)
Hainan	Pressure index	0.2221	0.0737	0.0363	0.1250
	State index	0.1430	0.1444	0.1162	0.1508
	Response index	0.2635	0.1351	0.1466	0.2061
	Composite index	0.6285 (IV)	0.3533 (I)	0.2991 (I)	0.4819 (III)
Shanghai	Pressure index	0.0885	0.0358	0.1344	0.2336
	State index	0.1933	0.1243	0.1305	0.1360
	Response index	0.1032	0.1856	0.2116	0.1178
	Composite index	0.3850 (II)	0.3457 (I)	0.4765 (III)	0.4874 (III)
Tianjin	Pressure index	0.0184	0.0299	0.0862	0.2336
	State index	0.2378	0.1555	0.0752	0.0798
	Response index	0.1171	0.2259	0.0865	0.2271
	Composite index	0.3734 (II)	0.4112 (II)	0.2479 (I)	0.5405 (III)
Zhejiang	Pressure index	0.0788	0.0634	0.0602	0.1810
	State index	0.1915	0.1474	0.1453	0.1060
	Response index	0.2446	0.1723	0.2281	0.1932
	Composite index	0.5149 (III)	0.3831 (II)	0.4336 (II)	0.4802 (III)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

Ecological security evaluation of cultivated land in grain balance areas

Table 4 shows the calculation results of the cultivated land ecological security level in the grain balance areas from 2007 to 2019. It can be seen that from 2007 to 2015, the fluctuation in the comprehensive index of Gansu, Guangxi, Ningxia and Chongqing increased; the comprehensive index of Guizhou, Shanxi, Shănxi and Xinjiang continued to decline; and the fluctuation in the comprehensive index of Qinghai and Yunnan decreased. From 2015 to 2019, the comprehensive index of Ningxia decreased, but the safety level remained unchanged; at the critical safety level, the comprehensive index of Qinghai decreased but the safety level remained unchanged; at the relatively unsafe level, the comprehensive index of Xinjiang decreased; and the ecological security level of cultivated land decreased to the relatively unsafe level. The comprehensive indexes of other provinces (cities and districts) improved, of which Gansu, Guangxi, Guizhou and Chongqing were at a relatively safe level; Shanxi and Yunnan were at a critical safety level; and Shaanxi was at a safe level. From the perspective of the pressure subsystem, the pressure index of all provinces (cities and districts) showed a downward change from 2007 to 2015, and the pressure index of all provinces (cities and districts) showed an upward change from 2015 to 2019. Regarding the state subsystem, from 2007 to 2015, the state indexes of Gansu, Guizhou, Ningxia, Qinghai, Shanxi, Xinjiang, Yunnan and Chongqing fluctuated and increased, while the state indexes of Guangxi and Shaanxi continued to decline. From 2015 to 2019, the state indexes of Gansu, Guangxi, Ningxia, Qinghai, Shanxi, Shănxi and Chongqing increased, and the state indexes of other provinces (cities and districts) decreased. From the response subsystem, the response indexes of all provinces (cities and districts) showed an upward change from 2007 to 2015. From 2015 to 2019, the response indexes of Gansu, Guangxi, Ningxia and Qinghai decreased, and the response indexes of other provinces increased.

Table 4. *Evaluation of cultivated land ecological security in main grain balance areas from 2007 to 2019*

Areas	Years	2007	2011	2015	2019
Gansu	Pressure index	0.1825	0.1258	0.0141	0.1692
	State index	0.0769	0.1709	0.1363	0.1709
	Response index	0.1766	0.1030	0.3255	0.3149
	Composite index	0.4360 (II)	0.3997 (II)	0.4759 (III)	0.6550（IV)
Guangxi	Pressure index	0.2250	0.1559	0.0562	0.0974
	State index	0.1472	0.1679	0.1094	0.1866
	Response index	0.0398	0.1152	0.3904	0.3095
	Composite index	0.4120 (II)	0.4389 (II)	0.5561 (IV)	0.5936 (IV)
Guizhou	Pressure index	0.2072	0.0786	0.0280	0.2057
	State index	0.0903	0.2436	0.1163	0.1136
	Response index	0.1378	0.3234	0.1469	0.3115
	Composite index	0.4354 (II)	0.6456 (IV)	0.2912 (I)	0.6308 (IV)
Ningxia	Pressure index	0.1113	0.0790	0.0489	0.1184
	State index	0.1051	0.1782	0.1806	0.2152
	Response index	0.1839	0.2117	0.2918	0.1674
	Composite index	0.4003 (II)	0.4690 (III)	0.5214 (III)	0.5010 (III)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

Qinghai	Pressure index	0.1192	0.0787	0.0275	0.1656
	State index	0.0692	0.1606	0.0977	0.1089
	Response index	0.1808	0.0847	0.2990	0.1716
	Composite index	0.3692 (II)	0.3240 (I)	0.4241 (II)	0.4461 (II)
Shanxi	Pressure index	0.2304	0.0992	0.0233	0.1356
	State index	0.0901	0.1064	0.1157	0.1662
	Response index	0.1641	0.1679	0.2112	0.2496
	Composite index	0.4846 (III)	0.3735 (II)	0.3502 (II)	0.5513 (III)
Shǎnxi	Pressure index	0.2319	0.1106	0.0224	0.1280
	State index	0.1631	0.1004	0.0561	0.1508
	Response index	0.0359	0.1074	0.2276	0.4390
	Composite index	0.4309 (II)	0.3184 (I)	0.3061 (I)	0.7178 (V)
Xinjiang	Pressure index	0.1938	0.1887	0.0448	0.0548
	State index	0.1517	0.1886	0.2104	0.1390
	Response index	0.1378	0.2728	0.2104	0.2407
	Composite index	0.4833 (III)	0.6501 (IV)	0.4656 (III)	0.4346 (II)
Yunnan	Pressure index	0.2336	0.1207	0.0147	0.0732
	State index	0.1040	0.1854	0.1371	0.1290
	Response index	0.1192	0.1198	0.1554	0.3517
	Composite index	0.4569 (III)	0.4260 (II)	0.3072 (I)	0.5539 (III)
Chongqing	Pressure index	0.1518	0.1298	0.0896	0.1514
	State index	0.0949	0.1683	0.1580	0.1898
	Response index	0.0611	0.1503	0.1212	0.2527
	Composite index	0.3078 (I)	0.4483 (II)	0.3688 (II)	0.5939 (IV)

Cultivated land ecological security evaluation and spatial heterogeneity analysis

The degree of obstacles to the ecological security of cultivated land in the main grain-producing areas

Table 5 shows the changes in the ecological security barriers of cultivated land in the main grain-producing areas from 2007 to 2019. It can be seen that the obstacle factors of each province changed greatly, mainly focused on the pressure subsystem indicators and response subsystem indicators. The two indicators of fertilizer application intensity and pesticide application intensity in most provinces gradually weakened in the research samples. In 2019, only the two provinces of Heilongjiang and Henan were the most important obstacle factors. The application strength of mulching film in Anhui, Hunan, Jiangsu, Jiangxi, Liaoning, and Sichuan was the most important obstacle. The number of rural cultural and technical training schools in Shandong and Inner Mongolia is the most important obstacle factor, and the proportion of the intermediate consumption of agricultural production in Hubei is the most important obstacle factor.

The degree of obstacles to the ecological security of cultivated land in the main grain sales areas

Table 6 shows the changes in the ecological security barriers of cultivated land in major grain sales areas from 2007 to 2019. It can be seen that the obstacle factors in

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

each province were similar to those in the main grain-producing areas, mainly focusing on the pressure subsystem indicators and response subsystem indicators. The fertilizer application intensity and pesticide application intensity in the pressure sub-system were highly impeded in 2007 and 2005. In 2019, the intensity of mulching film application in Fujian, Hainan, and Zhejiang was the most important obstacle factor, and the degree of obstacles between the intensity of fertilizer application and the intensity of pesticide application decreased. These two indicators of Beijing, Fujian, Shanghai, Tianjin, and Zhejiang are not shown in the statistical table. This shows that the "reduction and efficiency enhancement" actions in these provinces were relatively successful, effectively controlling the negative impact of chemical fertilizers and pesticides on the ecological safety of cultivated land. In addition, the obstacles to the number of rural cultural and technical training schools increased significantly in the sample.

The degree of obstacles to the ecological security of cultivated land in the grain balance areas

Table 7 shows the changes in cultivated land ecological security barriers in the grain balance area from 2007 to 2019. It can be seen that in 2007, the intensity of chemical fertilizer application in Gansu and Guangxi provinces was the main obstacle factor; the intensity of pesticide use in Guizhou, Qinghai and Chongqing provinces was the main obstacle factor; and the intensity of plastic film application in Shanxi and Shǎnxi provinces was the main obstacle factor. In 2019, the intensity of chemical fertilizer application, pesticide use and plastic film application in these provinces decreased significantly, while in Gansu and Guizhou, the intensity of plastic film application in Qinghai increased significantly. Although the impact of a certain index on the ecological security of cultivated land is controlled, the management of other pressure subsystem factors is ignored, so that the overall effect of agricultural non-point source pollution control is not significant. In addition, similar to the main grain-producing areas and grain balance areas, the common problem is that the barrier degree of the number of rural cultural and technical training schools increased significantly in the sample.

Table 5. *The ranking of ecological security obstacles of cultivated land in main grain-producing areas from 2007 to 2019*

Areas	Years	Obstacle ranking					Areas	Years	Obstacle ranking				
		1	2	3	4	5			1	2	3	4	5
Anhui	2007	P2	P1	R3	S2	S1	Jiangsu	2007	S1	P2	R3	P3	P1
	2015	R3	S4	P1	P2	S3		2015	R3	P3	S3	S2	P1
	2019	P3	S4	R4	R6	S2		2019	P3	R3	S2	S4	S3
Hebei	2007	S3	S2	R3	P2	P3	Jiangxi	2007	P1	P2	S2	S3	R3
	2015	R4	S3	P2	P1	S1		2015	S4	R3	S3	P3	P1
	2019	R3	S4	S1	R4	R7		2019	P3	S4	R5	R3	S3
Henan	2007	P2	R3	S2	S1	S3	Liaoning	2007	R3	S3	P1	S2	P2
	2015	R3	P2	S3	P1	P3		2015	R3	S1	P3	P1	S3
	2019	P1	R4	S3	S4	R7		2019	P3	R3	S4	P1	S3
Heilongjiang	2007	R3	P2	S3	S2	P3	Inner Mongolia	2007	P1	S2	S3	R3	R4
	2015	S4	R3	P1	P3	P2		2015	R3	S1	S4	P2	P1
	2019	P1	R3	S4	S3	R6		2019	R3	P3	S3	S4	P1

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

Hubei	2007	R3	P2	S2	S1	P3	Shandong	2007	S2	R3	P3	P2	P1
	2015	R3	P3	S4	S3	P1		2015	R3	P2	S3	P1	R5
	2019	R5	S4	S3	S2	R6		2019	R3	S4	S3	S2	R7
Hunan	2007	S2	R3	P2	S1	P1	Sichuan	2007	P2	S2	S3	P1	R6
	2015	S3	R3	P2	P3	P1		2015	R3	S4	P3	S1	P2
	2019	P3	S4	R3	R4	R5		2019	P3	S4	R3	R4	S3
Jilin	2007	S3	R3	S2	P1	P2							
	2015	R3	P2	S4	P1	S3							
	2019	R3	S3	P1	P3	S4							

P, S and R represent "Pressure," "State" and "Response." Figures represent specific indicators

Table 6. *The ranking of ecological security obstacles of cultivated land in major grain sales areas from 2007 to 2019*

Areas	**Years**	**Obstacle ranking**					**Areas**	**Years**	**Obstacle ranking**				
		1	**2**	**3**	**4**	**5**			**1**	**2**	**3**	**4**	**5**
Beijing	2007	S3	R3	S1	P3	P1	Shanghai	2007	S1	R3	P2	P3	P1
	2015	R3	P2	P1	S1	S4		2015	R3	S2	P1	P3	P2
	2019	R3	S1	S2	S4	R4		2019	R3	S2	S4	R4	R5
Fujian	2007	P2	P1	R3	S1	S3	Tianjin	2007	S2	R3	S3	P3	P1
	2015	S3	R4	P1	P2	P3		2015	P2	R3	S2	S3	S1
	2019	P3	S4	R3	S2	R5		2019	R3	S1	S2	S4	R7
Guangdong	2007	P2	S1	R3	R4	S4	Zhejiang	2007	S2	P2	P1	R4	R5
	2015	R3	S3	P2	P3	R4		2015	R3	S3	P3	S1	P2
	2019	R3	P3	S4	P1	S2		2019	P3	R3	S1	S3	R4
Hainan	2007	P2	S1	R3	R7	R5							
	2015	R3	S3	P1	P3	P2							
	2019	P3	S2	R3	S4	P1							

P, S and R represent "Pressure," "State" and "Response." Figures represent specific indicators

Table 7. *The ranking of ecological security obstacles of cultivated land in grain balance area from 2007 to 2019*

Areas	**Years**	**Obstacle ranking**					**Areas**	**Years**	**Obstacle ranking**				
		1	**2**	**3**	**4**	**5**			**1**	**2**	**3**	**4**	**5**
Gansu	2007	P1	R3	S1	S2	S3	Shanxi	2007	P3	R3	S1	S2	R4
	2015	R3	P2	S3	P1	S4		2015	R3	S3	P2	P1	P3
	2019	P3	R3	S4	S1	R7		2019	R3	S4	P3	S2	P1
Guangxi	2007	P1	S2	R3	P2	S1	Shǎnxi	2007	P3	S2	R3	S3	R4
	2015	R4	S3	P3	P1	S4		2015	R3	P2	P3	R4	S3
	2019	R3	S3	P3	S4	P1		2019	R7	R5	S4	P3	S1
Guizhou	2007	P2	R3	S1	S2	S4	Xinjiang	2007	S2	R3	P2	P3	S1
	2015	R3	S3	P2	P1	P3		2015	S3	S4	R3	P3	P1
	2019	P3	S3	R6	S4	R5		2019	R3	S3	S4	P3	P1

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

Ningxia	2007	R3	P1	P2	S3	S2	Yunnan	2007	R3	S1	S2	S3	R6
	2015	S4	S3	P3	R4	P1		2015	R3	S3	P2	P1	P3
	2019	S4	P3	R3	P1	R5		2019	R4	S3	P3	S4	P2
Qinghai	2007	P2	R3	S3	S2	P1	Chongqing	2007	P2	S3	R3	S2	S1
	2015	R4	S3	R5	P1	P3		2015	R3	P1	P3	S1	S3
	2019	P3	R3	S3	S4	S1		2019	R3	P3	S4	P1	S2

P, S and R represent "Pressure," "State" and "Response." Figures represent specific indicators

Discussion

The policy of reducing emissions and increasing efficiency formulated by the Chinese government has indeed played a positive role. Regarding the change trend, the amount of chemical fertilizer and pesticide is decreasing, but the amount of plastic film is increasing. In the previous analysis of obstacle factors, the main obstacle factor in many provinces is the intensity of plastic film use, which also reflects this. This shows that the policy still lacks pertinence and has not been updated in accordance with the characteristics of different types of pollution. In fact, many countries and regions have proposed more specific policy tools when dealing with agricultural non-point source pollution internationally. For example, the use of nitrogen fertilizer has led to excessive nitrogen emissions, and many countries have conducted assessments of nitrogen emissions. Examples of conceptual frameworks for nitrogen issues are found in the reports prepared by the United States (US) Environmental Protection Agency (EPA), the European Nitrogen Assessment (ENA) (Sutton et al., 2011), and the Indian Nitrogen Assessment (Cunha-Zer et al., 2021). In order to prevent the impact of nitrate discharged from agriculture on water bodies, the EU proposed the nitrates directive (ND) and the sustainable use of pesticides directive (SUPD) (Wuijts et al., 2021).

The EU proposes to reduce the use of chemical pesticides by 50% by 2030, and plans to issue the first binding regulation on the sustainable use of pesticides in the future. The law requires farmers to reduce their use of agricultural chemicals. In the next decade or so, the European Union will encourage farmers to adopt integrated pest management (IPM) to prevent and control agricultural diseases and pests. In addition, the EU has proposed the "action plan for the development of organic production", which requires that by 2030, the proportion of organic cultivation in agricultural land should reach 25%, the use and risk of pesticides should be reduced by 50%, and the use of chemical fertilizers should be reduced by at least 20%. This plan is consistent with the goal proposed in the "European Green agreement." Within the European Union, regulatory tools (EU nitrate directive) and incentive plans for individual farms (agricultural environment plan) are still the main policy tools used to control nitrate pollution in agricultural diffusion (Amblard et al., 2021). For agricultural plastic film, the European Union has also proposed targeted policies. In the 2018 European plastic circular economy strategy, the European Commission (EC) identified a series of actions to reduce plastic pollution in the coming decades. Of course, plastic waste from agriculture is also a major consideration (Pazienza et al., 2021). At the same time, eight countries in the European Union have adopted the extended producer responsibility (EPR) program to manage plastic waste in the agricultural sector (Leal et al., 2021).

China's real control of agricultural non-point source pollution was established in 2015, which included reducing chemical fertilizers and pesticides. Its management of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

plastic film is relatively weak. In 2020, the utilization rate of chemical fertilizers for the three major grain crops of rice, wheat and corn in China was 40.2%, and the utilization rate of pesticides was 40.6%. By 2025, the utilization rate of chemical fertilizers and pesticides for major crops will reach 43%. Compared with the international agricultural non-point source pollution control policy, China needs to improve its policy in combination with international experience due to its delayed application of treatment. For example, we should not only reduce the amount of fertilizer, pesticide and plastic film, but also pay attention to the impact of these factors on the environment. It is also necessary to formulate policies for specific pollutants to improve the effect of treatment.

Conclusions

We selected 14 indicators, namely, fertilizer application intensity, pesticide application intensity, intensity of mulching film application, water–soil coordination, reclamation rate, multiple crop index, grain production per unit area, forest cover rate, per capita net income of farmers, number of rural cultural and technical training schools, proportion of farmers' agricultural investment in fixed assets, proportion of agricultural production intermediate consumption, proportion of water-saving irrigation, mechanization level to build the PSR cultivated land ecological security evaluation system. The statistical data of 30 provinces (cities and districts) from 2007 to 2019 were selected for the improved entropy method to evaluate the ecological security of cultivated land. Considering that the sample was too large, 2007, 2011, 2015, and 2019 were selected for the comparative analysis. On this basis, a barrier degree model was constructed to analyze the critical degree of the impact of each evaluation index on the ecological security of cultivated land, and find out the obstacle factors of the ecological security of cultivated land. The main conclusions are as follows:

(1) Overall, before the implementation of the reduction and efficiency increase in 2015, the functional areas were basically at a relatively unsafe level, the cultivated land was seriously damaged and the productivity of cultivated land was weakened. The pressure index decreased significantly, especially in the main grain-producing areas and grain balance areas, which shows that the agricultural non-point source pollution caused by agricultural production factors, such as chemical fertilizer, pesticide and plastic film, has a serious negative impact on the cultivated land ecology in the region. In order to ensure grain output, ignoring the deterioration of resources and the environment, there are defects in the resource allocation and management level; the fluctuation in the state index also shows that the utilization degree of cultivated land is changing; the continuous improvement of the response index means that agricultural production policy and environmental governance policy are constantly advancing. Due to the limited amount of cultivated land in the main grain sales areas, although the pressure index has increased compared with other regions, in order to produce enough food from the limited cultivated land, the investment in agricultural production must be increased; the continuous decline in the state index and the continuous rise of the response index show the excessive food production on the limited cultivated land in the food balance area and the government's efforts to improve the ecological security of cultivated land, respectively. Since 2015, the ecological security level of cultivated land in the three functional areas has been improved, the contribution of each subsystem index has been improved, and the reduction and efficiency increase have achieved good results in the region.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2006_52935316

(2) From the perspective of main grain-producing areas, the ecological security evaluation grade of cultivated land in most provinces was low from 2007 to 2015, and the cultivated land was damaged to a certain extent. Except for Hubei and Jiangsu, the pressure index of other provinces continued to rise, and the pressure index of other provinces decreased. The negative effects of chemical fertilizers, pesticides and plastic films are becoming increasingly prominent. During this period, the provinces, as the main grain-producing areas, blindly pursued grain output and used agricultural production factors unreasonably, threatening the ecological security of cultivated land. The fluctuation in the state index of Hebei, Jiangsu and Shandong decreased. During this period, the three provinces demonstrated the unreasonable use of cultivated land, resulting in problems in the state of cultivated land. The response index of Heilongjiang, Jiangxi and Sichuan decreased, and the regional policies did not provide corresponding help to improve the ecological security of cultivated land, resulting in the reduction in response contribution. After the implementation of the reduction and efficiency increase policy in 2015, the pressure index of each province increased, and the unreasonable investment in chemical fertilizer, pesticide and plastic film improved, reducing the impact of non-point source pollution on the ecological security of cultivated land. The state index of Henan, Heilongjiang, Jilin, Liaoning and Inner Mongolia decreased. Although the input of agricultural production factors was controlled, the mode of agricultural production was not effectively improved; from 2015 to 2019, the response index of Hebei, Liaoning and Shandong decreased, reflecting the loopholes in policy implementation in these three provinces. Combined with the results of obstacle factors, it was found that there were differences in obstacle factors in different provinces in the main grain-producing areas, in which chemical fertilizers and pesticides were effectively controlled, but there were still some problems. The application intensity of chemical fertilizers in Heilongjiang and Henan provinces in 2019 was still the main obstacle factor. As a large grain production province, grain production scale was large, and chemical fertilizer was still an important factor to ensure regional grain output. The government needs to control the use of chemical fertilizer by establishing and improving the reward and punishment mechanism, standardizing farmers' production behavior, strengthening technical training, among other actions. The application intensity of plastic film in Anhui, Jiangsu, Liaoning and Sichuan is the main obstacle factor. It is necessary to strengthen the recovery of plastic film, promote the use of degradable plastic film, reduce the residue of plastic film and improve the ecological security of cultivated land. In addition, it should also be noted that the ecological security evaluation level of cultivated land in Jilin and Liaoning is critical, and the ecological security evaluation level of cultivated land in Inner Mongolia is relatively unsafe. Government departments need to take targeted measures to intervene to prevent the further destruction of cultivated land.

(3) From the perspective of the main grain sales areas, compared with the main grain production areas, the cultivated land security evaluation level of all provinces (cities and districts) is lower. This shows that although the main grain sales areas do not bear the responsibility of national grain supply, there are still small farmers in this grain-planting area, who are more backward in their planting methods and management types, resulting in the declining quality of cultivated land. In addition, it cannot be ignored that other types of agriculture in the main grain sales areas, such as flowers, vegetables and fruits, have a large production scale and need to use a large amount of pesticides, which will also indirectly affect the ecological quality of cultivated land. Regarding the

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obstacle factors, it can also be seen that the pesticide use intensity in Fujian, Guangdong, Hainan and Tianjin has become the main obstacle factor in the research range, which can also reflect this situation. Similar to the main grain-producing areas, from 2007 to 2015, except that the pressure index of Hebei and Guangdong increased to some extent in 2011, all provinces (cities and districts) showed a downward change in 2015, and the pressure index of all provinces (cities and districts) increased after 2015, indicating that the action of reduction and efficiency increase has played a certain governance effect. From the perspective of the state subsystem, the fluctuation in the state index in Beijing, Guangdong, Tianjin, Zhejiang, Fujian, Hainan and Shanghai decreased from 2007 to 2015. Farmers' unreasonable use of cultivated land is serious, which exacerbates the destruction of the cultivated land ecosystem, and the uncontrolled use of cultivated land leads to the weakening of cultivated land fertility, which restricts the ecological security of cultivated land. Since 2015, the status index of Beijing and Zhejiang has continued to decline, which requires the attention of government departments. Regarding the change in the response index, there was a decline in the index in all provinces (cities and districts) before and after 2015. All regions need policy intervention according to their own actual situation to prevent the recurrence of cultivated land problems. In 2019, the intensity of plastic film application in Fujian, Hainan and Jiangsu was the main obstacle factor, which also needs to be managed by local governments to control the white pollution caused by plastic film.

(4) From the perspective of the grain balance areas, the comprehensive index of each province changed differently from 2007 to 2015, among which Guangxi changed to a safer level; Gansu, Ningxia and Xinjiang changed to a critical safe level; Qinghai, Shanxi and Chongqing changed to a less safe level; and Guizhou, Shănxi and Yunnan changed to an unsafe level. From 2015 to 2019, the ecological security level of cultivated land in Ningxia and Qinghai remained unchanged; Xinjiang was at a relatively unsafe level; Gansu, Guangxi, Guizhou and Chongqing were at a relatively safe level; Shanxi and Yunnan were at a critical safety level; and Shănxi was at a safe level. Generally speaking, the ecological security of cultivated land in Xinjiang and Qinghai has been greatly affected. The economic development of these two provinces is relatively backward, and there are some disadvantages in terms of the scientific and technological level and management ability, which need to be supported by national policies. Regarding the change in each subsystem, the pressure index before the implementation of reduction and efficiency measures increased; all provinces (cities and districts) in the grain balance areas showed a downward change; and the pressure index of all provinces (cities and districts) showed an upward change, which reflects that the region has achieved good results in controlling agricultural non-point source pollution as a whole, and has paid more attention to agricultural non-point source pollution and cultivated land protection. The status index before and after the implementation of reduction and efficiency increases. There was also a decline in some provinces (cities and districts); in response, the response indexes of all provinces (cities and districts) showed an upward change from 2007 to 2015, but decreased in Gansu, Guangxi, Ningxia and Qinghai after 2015. Attention and intervention are needed to strengthen the implementation of policies to ensure the effective control of agricultural non-point source pollution, ensure the ecological security of cultivated land and realize food security. Combined with the analysis of obstacle factors, due to the division characteristics of functional areas, the grain balance area has certain grain production conditions, but it is weaker than the grain functional area and basically realizes self-

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sufficiency. Therefore, in terms of the input of agricultural production factors, although the early use of chemical fertilizer, pesticide and plastic film was unreasonable, the agricultural non-point source pollution was gradually aggravated. However, after the implementation of reduction and efficiency increase, the input of agricultural production factors was controlled to a certain extent, which is proved by the significant decline in the application intensity of chemical fertilizer, pesticide and plastic film in 2019. It is worth noting that the application intensity of plastic film in Gansu, Guizhou and Qinghai has increased significantly. The application intensity of plastic film in Gansu, Guizhou and Qinghai has become the main obstacle factor to the ecological security of cultivated land in this province, which requires guidance and treatment from the government.

Acknowledgements. We gratefully acknowledge financial support from the National Social Science Foundation of China (NO.20FGLB059).

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