The effect of human capital and S&T innovation on the agricultural output efficiency of pesticide use in China

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Abstract

Pesticides are important materials for agricultural production, and that increasing the output efficiency of pesticide use will promote green agricultural upgrading, which needs to integrate the scientific and technological innovation and human capital to form a virtuous development circle. By collecting large amounts of data and accounting the output efficiency of agricultural pesticide application in various provinces and cities in Chinese main land, the influence mechanism of human capital and scientific and technological innovation on the output efficiency of pesticide application has been analyzed with the help of factor model. Results show that the amount of pesticide application has increased from 0.733 million tons to 1.313 million tons in China from 1990 to 2020. During the same period, the added value of agriculture, forestry, animal husbandry and fishery per unit of pesticide increased by 3.19 times, and the added value of agriculture and forestry per unit of pesticide increased by 2.61 times at the prices in 1990. The scientific and technological innovation and human capital have significant positive impact on the output efficiency of agricultural pesticide application, but their cross item has a negative effect. Scientific and technological innovation is the basis for talents playing the roles. It is necessary to enhance the fusion of agricultural S&T and human capital, perfect the financial support policy, reform land circulation system, and strengthen agricultural infrastructure so as to increase the output efficiency of pesticide application and keep agriculture develop sustainably.

KEY WORDS

Pesticide application efficiency, influencing factors, empirical analysis, countermeasures and suggestions

JEL CLASSIFICATION

C21, D22, D24, I25, Q15

1 | INTRODUCTION

Rural revitalization is a major national development strategy in China, which ensures steady agricultural production growth, steady increase in farmers' incomes, and steady stability and tranquility in rural areas. The actions carrying out green, efficient and high-quality development open scientific way for China's agricultural production, which should implement water saving and reduce the use of chemical fertilizers and pesticides. The ministry of agriculture of China has promoted the "Zero Growth in Pesticide Use Action" to boost the transformation and upgrading of agriculture. "We will intensify efforts to control pollution from non-point agricultural sources, carry out the campaign to save agricultural fertilizer and drugs, and achieve a negative growth in the use of chemical fertilizers and pesticides." (The CPC Central Committee & the State Council, 2019) .

Pesticides are indispensable materials for agricultural production. That studying the output efficiency of pesticide application can help reduce the man-made pollution in the agricultural production process and improve the quality of agricultural products fundamentally. According to the statistical data, since 2014 the total amount of pesticides used has been increasing negatively year by year in China. What is the agricultural added value efficiency of each unit of pesticide use? What are the factors influencing the efficiency? How do farmers achieve high-quality and high-efficiency performance in agricultural process? These are the key issues to achieving the benign development of agriculture, rural areas and farmers.

2 | LITERATURE REVIEW

Extant related literature mainly studies the influencing factors of agricultural farmland efficiency and pesticide use. The factors affecting the agricultural output efficiency of farmland are such as the average household farmland area and the intensive degree (Liu & Yu, 2010), climate conditions, agricultural machinery and technology (Zhou & Ma, 2022), foreign direct investment, and education level (Xiao, 2012), water conservancy infrastructure (Shi, 2015), multiple-cropping index, planting structure, chemical fertilizer application per unit area, electricity consumption per unit of cultivated land area, the rate of agricultural employees, the effective irrigation rate, forest land coverage rate, and the proportion of financial support for agriculture (Wu & Qi, 2020). Factors affecting pesticide use include sown area, the adjustment of drug intensity of each crop and planting structure (Qiu & Hu, 2020), farmers' perception of the pesticide properties (Ma & Huo, 2015), application behavior and risk preference (Jiang, Zhou & Sun, 2017).

However, the extant literature has pay little attention to analyzing the agricultural output efficiency of pesticide application, that is, the change in economic output efficiency of pesticide use and its influencing factors have been studied little. Only green and high efficiency can achieve a virtuous cycle of agricultural development. Scientific and technological innovation and human capital are the keys to high-quality development in agriculture. That analyzing the impact of S&T innovation and human capital on the output efficiency of pesticide use and exploring the effect of fertilizer use intensity and other factors can provide policy inspiration for the green development of agriculture in China.

3 | METHODS

3.1 | Analysis of the output efficiency of pesticide use in China

Since 1990, pesticide use in China has increased from 733,000 tons to 1.8077 million tons in 2013, and gradually decreased from then to 1.313 million tons in 2020, with an increase by 1.79 times between 1990 and 2020. At the nominal price, the added value of agriculture, forestry, animal husbandry and fishery(AFHF) increased by 17.98 times, from 766.21 billion yuan in 1990 to 13,778.22 billion yuan in 2020, and the added value of agriculture and forestry(AF) increased by 14.70 times, from 528.46 billion yuan in 1990 to 7,770.98 billion yuan in 2020. At the price of 1990, the added value of AFHF increased by 5.71 times from 1990 and 2020, and the added value of AF increased by 4.67 times.

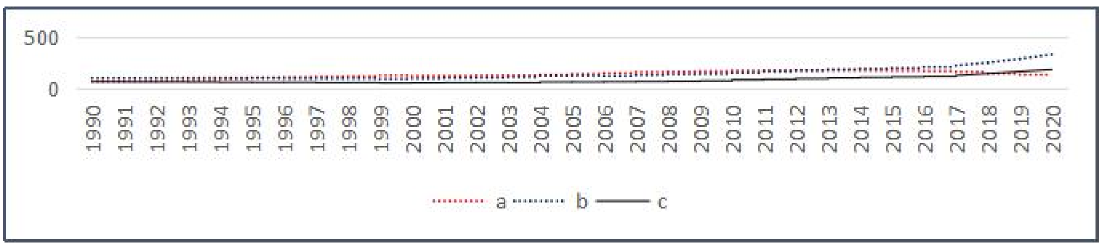

FIGURE 1 China's agricultural pesticide use, the output efficiency of unit pesticide application

a: the amount of pesticide used. b: the added value of agriculture, forestry, animal husbandry and fishery per ton of pesticide. c : the added value of agriculture and forestry per ton of pesticide.

According to the price in 1990, the agricultural added value of AFHF per ton of pesticide use in China increased from 1.05 million yuan in 1990 to 3.33 million yuan in 2020, the added value of AF per ton of pesticide use increased from 0.72 million yuan to 1.88 million yuan in 2020. Among them, the added value of AF per ton of pesticide use gradually decreased down from 0.72 million yuan in 1990 to 0.32 million yuan in 2003, and during this period pesticide application was decoupled from the output efficiency and agricultural economic growth (Yu & Zhang, 2018). From 2004 to 2020, the added value of AF per ton of pesticide application in China increased from 0.69 million yuan to 1.88 million yuan in 2020, and the output efficiency of pesticide application increased by 2.72 times. The pesticide usage and the output efficiency of pesticide application of 31 provinces and cities in mainland China are shown as Table 1.

TABLE 1 Pesticide use and output value added in provinces and cities in China(main land)

	Pesticide usage (ten thousand tons)				**Add value of agriculture and forestry per ton of pesticide use (10,000 yuan / ton)**				**Increase multiple of pesticide consumption per unit of planting area**
Regions	**1991**	**2010**	**2018**	**Increased multiple**	**1991**	**2010**	**2018**	**Increased multiple**	
Beijing	0.73	0.4	0.26	-0.64	40.09	80.55	124.66	2.11	1.0246
Tianjin	0.25	0.37	0.22	-0.12	77.85	92.11	159.91	1.05	0.1910
Hebei	4.68	8.46	6.15	0.31	33.12	82.57	124.20	2.75	0.4132
Shanxi	0.69	2.61	2.65	2.84	68.54	62.63	70.85	0.03	3.2898
Inner Mongolia	0.51	2.43	2.96	4.80	128.55	107.80	120.74	-0.06	2.1361
Liaoning	1.87	6.94	5.51	1.95	57.57	42.66	64.98	0.13	1.5479
Jilin	0.79	4.28	5.1	5.46	108.73	59.28	42.55	-0.61	3.3166
Heilongjiang	0.84	7.38	7.42	7.83	141.06	51.04	106.26	-0.25	4.1862
Shanghai	1.44	0.7	0.32	-0.78	13.28	40.51	72.70	4.47	-0.5072
Jiangsu	7.24	9.01	6.96	-0.04	30.56	72.67	133.70	3.38	0.0344
Zhejiang	5.87	6.51	4.37	-0.26	25.32	52.45	93.96	2.71	0.6479
Anhui	3.81	11.66	9.42	1.47	32.40	36.73	59.60	0.84	1.3103
Fujian	3.41	5.82	4.91	0.44	28.94	51.91	87.85	2.04	1.5807
Jiangxi	3.59	10.65	7.72	1.15	32.44	26.11	53.06	0.64	1.2565
Shandong	5.96	16.49	12.99	1.18	56.28	54.77	78.96	0.40	1.1638
Henan	3.88	12.49	11.36	1.93	60.06	70.44	88.93	0.48	1.3770
Hubei	5.12	14	10.33	1.02	35.45	37.48	69.86	0.97	0.8834
Hunan	6.26	11.88	11.42	0.82	30.21	54.64	63.39	1.10	0.8083
Guangdong	8.07	10.44	9.37	0.16	29.20	53.33	88.33	2.03	0.5354
Guangxi	2.42	6.45	6.97	1.88	49.68	66.49	104.14	1.10	1.5689
Hainan	0.68	4.55	2.32	2.41	47.45	27.46	80.65	0.70	2.9672
Chongqing	4.4	2.09	1.72	0.56	70.09	95.44	203.58	1.90	0.5299
Sichuan		6.22	5.13	0.56	70.09	99.76	207.37	1.96	0.5299
Guizhou	0.46	1.29	1.11	1.41	160.80	131.22	490.93	2.05	0.6777
Yunnan	1	4.62	5.26	4.26	111.70	65.38	113.22	0.01	2.5114
Tibet	0.04	0.1	0.1	1.50	150.29	131.38	204.26	0.36	0.9972
Shaanxi	1.07	1.24	1.26	0.18	79.36	233.37	386.74	3.87	0.4053
Gansu	0.49	4.46	4.29	7.76	86.36	41.20	56.25	-0.35	7.3223
Qinghai	0.2	0.21	0.18	-0.10	38.17	112.29	199.01	4.21	-0.1230
Ningxia	0.13	0.26	0.23	0.77	97.30	178.79	289.77	1.98	0.3688
Xinjiang	0.64	1.82	2.37	2.70	127.82	186.84	183.60	0.44	0.8525

Note: From 1991 to 1996, the use of pesticides, the added value of agriculture and forestry per unit of pesticides were calculated by the combined data of the two places of Sichuan and Chongqing.

Between 1991 and 2018, The growth multiples of pesticide application are negative in 6 regions including Shanghai, Beijing, Zhejiang, Tianjin, Qinghai and Jiangsu, which were -0.78, -0.64, -0.26, -0.12, -0.10 and-0.04 respectively. Among of the other 25 regions, the larger growth multiples are Heilongjiang (8.83times), Gansu (8.76 times), Jilin (6.46 times), Inner Mongolia (5.80 times), Yunnan (5.26 times); The amount of pesticide applied per unit of planting area has changed as follows: only Shanghai and Qinghai have decreased by 0.51 times and 0.12 times, respectively, and the other 29 provinces and cities witness positive growth. Among of them, there are 7 regions which pesticide application per unit planting area have increased more than 3 times, such as Gansu (8.32 times), Heilongjiang (5.19 times), Jilin (4.32 times), Shanxi (4.29 times), Yunnan (3.51times), Hainan (3.97 times) and Inner Mongolia (3.14 times).

The added value efficiency of pesticide use between provinces and cities are different. From 1991 to 2018, the added value of AF per unit of pesticide application increased positively in 27 provinces and cities. Among them, Shanghai, Qinghai, Shaanxi, Jiangsu, Hebei, Zhejiang, Beijing, Guizhou, Fujian and Guangdong increased more than twice. However, the added value of AF per unit pesticide application increased negatively in Jilin, Heilongjiang, Gansu and Inner Mongolia at the same time.

3.2 | The determinants of the output efficiency of pesticide use

The agricultural output added value efficiency of AF of pesticide use is affected by pesticide quality, application technology and other factors, among which agricultural science and technology innovation, agricultural human capital and their fusion play a key role, while other factors are incorporated into the analysis as control variables.

Scientific and technological innovation is the source of driving force for development and also is the fundamental driving force for green and efficient agricultural development. Schumpeter (1914) summarized innovation into new raw materials, new products, new production processes, new markets and new organizations, or into combinations of them. Scientific and technological innovation can affect the agricultural output added value efficiency of AF of pesticide use from both agricultural production and pesticide use.

Firstly, scientific and technological innovation can improve seeds, derive new agricultural products, increase agricultural yield and product quality, or enhance insect resistance of crops, reduce pesticide use (Dobson, Scheyer & Rizet et al., 2006). Secondly, innovation may improve agricultural production machinery, cultivation, chemistry and biotechnology, ameliorate soil structure and fertility, research and develop highly efficient and easily decomposed pesticide preparation (Helepciuc & Todor, 2021), and develop comprehensive pest prevention technology (Dong & Zheng, 2019), which helps increase agricultural output and reduce pesticide use per cultivating area. Thirdly, scientific and technological innovation and its use promotes agricultural management, strengthens the supervision of crop and detection and forecasting insect pests and diseases, fertilizes and controls pests scientifically and timely, reduces pesticide residues and improves product quality (Gauchan, Joshi & Biggs, 2003), opens up new markets, enhances the efficiency of agricultural output, increases the green added value of agricultural products (Lizotte, Locke & Testa, 2014), which improves the output performance of pesticide use.

Human capital is the productive factor with initiative, and the quality of rural labor force is the most critical factor for the high quality development in agriculture, Through scientific production arrangement, innovative cultivation, insect control technology, improving product harvest, storage and marketing (Hall, Clark & Naik, 2007), etc., the improvement of human capital quality can reduce the input cost, increase operating income, directly affect the added value efficiency of AF per unit pesticide use (Taweekul, Caldwell & Yamada et al., 2009). If the high-quality agricultural labor force and scientific and technological innovation are integrated, a virtuous cycle of green agricultural development will be built.

In addition to scientific and technological innovation and human capital, the other factors affecting the output efficiency of agricultural pesticide application include factors such as agricultural production mechanization level, irrigation conditions, multiple cropping index, fertilization intensity, sowing scale, forest scale, intensity degree, disaster degree, and financial support for agriculture (Tuan & Zhang, 2021). To sum up, the influencing factor model of agriculture and forestry added value per unit of pesticide application can be set as follows:

$$y = f(rd, h; z) \tag{1}$$

where, y is the output added value per unit pesticide application, rd is scientific and technological innovation, h is human capital, and z is the control variable vector.

TABLE 2 Description of the variables and indicators

	Explaining variables	Code	Calculating formulas	Data sources
Explanatory variables	S&T input	*rd*	Science and technology investment * Agricultural science and technology investment ratio / agricultural added value	China Statistical Yearbook, China Rural Statistical Yearbook, China Statistical Yearbook of Science and Technology
	human capital	*h*	The proportion of agricultural labor force in high school education and above (%)	
Controlled variables	Mechanized level	*m*	Agricultural mechanical power per unit of cultivated area (kw / ha)	
	irrigation conditions	*r*	Effective irrigation area / cultivated land area	
	multiple-crop index	*f*	Total crop sown area / cultivated land area	
	Fertilization intensity	*e*	Total chemical fertilizer application / total sown area	
	Sowing scale	*b*	Total crop sown area	
	Intensive degree	*s*	Cultivated land area / agricultural labor force	
	Proportion of disaster	*a*	Disaster formation area / total sown area	
	Fiscal support for agriculture	*p*	Fiscal expenditure on agriculture, forestry and water resources / total added value of agriculture	

3.3 | Descriptive analysis

The ratio of total R&D investment to GDP in provinces and cities is used to indicate the intensity of investment in agricultural science and technology in China. The proportions of agricultural labor force with high school education (including technical secondary school) and above college education were collected from 1990 to 2012, and the proportion of agricultural labor force with college education from 2013 to 2018 was estimated according to the data model of population education level. The descriptive analysis of the main indicator series is as shown in Table 3.

TABLE 3 Descriptive analysis of the main indicators

Variables	Unit	Maximum	Minimum	Mean	No.
The added value of *AFHF* per unit pesticide	10,000¥ / ton	1009.13	22.54	135.22	930
The added value of *AF* per unit pesticide	10,000¥ / ton	490.93	13.28	77.22	868
R&D intensity	%	10.73	0.15	1.72	868
High school agricultural workforce	%	41.86	0.09	11.79	868
Agricultural labor force college or above	%	16.96	0.01	1.70	868
Mechanized level	kW / hectare	17.14	1.33	6.09	868
irrigation conditions		1.03	0.19	0.52	868
multiple-crop index		2.55	0.49	1.37	868
Fertilization intensity	Ton / hectare	0.80	0.08	0.30	868
Sowing scale	1000 hectares	14829	104	5052	868
Intensive degree	hectare/ person	2.19	0.13	0.52	868
Proportion of disaster		0.48	0	0.14	868
Fiscal support for agriculture	%	4.76	0	0.44	868

At the price in 1990, the average added value of AFHF per ton of pesticide application, and the average added value of AF per ton of pesticide application in provinces and cities in China were 1.35 million yuan and 0.77 million yuan from 1991 to 2018, respectively, but the gap between minimum and maximum value of output efficiency per ton of pesticide application were 43.7 times and 36 times respectively. The highest investment intensity in agricultural research and development was 10.73% in Beijing in 1993, and the lowest investment intensity was 0.15% in Hainan in 1999. The proportions of agricultural labor force with senior high school education and college education above are quite different among regions. The education level of agricultural labor force in eastern Chinese regions is relatively high, but the education level of agricultural labor force in western China regions is very low.

Farmland irrigation conditions, multiple cropping index, cultivated land fertilizer application intensity, and cultivated land area per unit agricultural labor force are also quite different among regions.

3.4 | Determinants of output value added in pesticide application

According to formula (1), the corresponding econometric model is：

$$y_{it} = \alpha_0 + \alpha_1 rd_{it} + \alpha_2 h_{it} + \beta z_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (2)$$

The unit root tests of the data series show that the added value of AFHF per unit of pesticide use, added value of AF per unit of pesticide use, and sown area are integrated of order 1 and the log value of these data series are stationary, and the other data series are stationary. Through Hausman test, the fixed-effect are adopted to regression model, and the residuals are tested being stationary so the co-integration are established. After the benchmark regression analysis, the TSLS regression analysis have been performed with the lagging first-stage series of the explanatory variables as the instrumental variables in order to prevent the endogeneity of explanatory variables. The results are shown in Table 4.

TABLE 4 Analysis of the influence factors of agricultural added value of pesticide application

Explanatory variables	31 provinces and cities in mainland China (benchmark regression)		31 provinces and cities in mainland China (TSLS)	
	ny	nl	ny	nl
c	6.69^{***}	5.74^{***}	6.63^{***}	5.46^{***}
	(0.18)	(0.13)	(0.12)	(0.11)
rd	2.21^{**}	2.65^{*}	2.17^{**}	2.70^{*}
	(0.78)	(1.50)	(1.08)	(1.43)
h	0.14^{***}	0.13^{***}	0.15^{***}	0.12^{***}
	(0.03)	(0.04)	(0.02)	(0.02)
rd*h	-2.95^{***}	-1.96^{***}	-2.88^{***}	-1.97^{***}
	(0.48)	(0.42)	(0.47)	(0.43)
m	0.015^{***}	0.01^{***}	0.014^{***}	0.01^{***}
	(0.006)	(0.005)	(0.005)	(0.004)
p	0.18^{***}	0.17^{***}	0.19^{***}	0.18^{***}
	(0.06)	(0.04)	(0.05)	(0.05)
e	-0.86^{***}	-0.94^{***}	-0.88^{***}	-0.96^{***}
	(0.09)	(0.16)	(0.09)	(0.17)
s	0.18^{***}	0.31^{***}	0.17^{***}	0.32^{***}
	(0.02)	(0.03)	(0.02)	(0.03)
a	-0.85^{***}	-1.07^{**}	-0.87^{***}	-1.09^{**}
	(0.13)	(0.48)	(0.12)	(0.42)
lnb	-0.17^{***}	-0.15^{***}	-0.19^{***}	-0.12^{***}
	(0.01)	(0.01)	(0.01)	(0.01)
f	-0.27^{***}	-0.18^{***}	-0.26^{***}	-0.20^{***}
	(0.04)	(0.03)	(0.04)	(0.03)
effect	Fixed	Fixed	fixed	fixed
Ob.	868	868	837	837
ad.R2	0.61	0.57	0.53	0.48
D.W.	2.14	2.09	2.17	2.10

Note: 1. ny and nl are the logarithm of added value of *AFHF* per unit of pesticide application, and logarithm of added value of *AF* per unit of pesticide application, respectively; 2. The values of the parentheses are the corresponding parameter standard errors, and the stars * * *, * *, and * indicate the 1%, 5%, and 10% significant levels, respectively. The same is as table 5.

First, the factors influencing the productivity of AFHF have been analyzed. The dependent variables are the logarithm of added value of AFHF per unit of pesticide application, and the logarithm of added value of AF per unit of pesticide application respectively. R&D investment increases by 1%, can improve the added value of AFHF per unit of pesticide application by 2.21% and the added value of AF per unit of pesticide application by 2.65%. The proportion of agricultural labor with high school education has no significant effect on the added value of pesticide application, but the proportion of agricultural labor above college increases by 1%, can promote the added value of AFHF per unit of pesticide application by 0.14%, and increase the added value of AF per unit of pesticide application by

0. 13%. However, the cross term of the intensity of R&D investment and the proportion of labor force above college shows negative impact, which indicates that the integration of them is not close enough. In addition, agricultural machinery power, cultivated land intensity and financial support for agriculture have a positive impact on the added value per unit of pesticide application, while chemical fertilizer application intensity, replanting index, disaster rate and cultivated land scale impose negative effect on the added value per unit of pesticide application, and the impact of irrigation conditions is not significant so the variable code does not appear in the regression equations.

TABLE 5 Analysis of factors influencing pesticide application in heterogeneous areas

	Low efficiency area		**Low- medium efficiency areas**		**Medium - high efficiency area**		**High efficiency area**
	ny	**nl**	**ny**	**nl**	**ny**	**nl**	**nl**
c	3.33***		4.73***	4.22	5.90***	5.44***	4.41***
	(0.14)		(0.31)	(0.31)	(0.26)	(0.25)	(0.08)
rd	37.5***	50.19***	6.3***	8.99***	15.59***	11.24***	12.1***
	(11.9)	(16.1)	(1.57)	(2.6)	(3.57)	(3.3)	(2.4)
h	0.31***	0.32***	0.09***	0.03***	0.24***	0.23***	
	(0.13)	(0.13)	(0.02)	(0.01)	(0.03)	(0.03)	
*rd*h*	-24.7***	-34.4***	-0.3***	-0.54	-6.52***	-6.95***	
	(10.9)	(14.6)	(0.05)	(0.3)	(1.15)	(1.0)	
m	0.03***	0.04**	0.03***	0.04***			-0.05***
	(0.01)	(0.02)	(0.006)	(0.005)			(0.01)
p		0.92***	0.1***	0.04	1.06***	1.18***	0.33***
		(0.4)	(0.04)	(0.04)	(0.18)	(0.18)	(0.07)
e		-2.1**	-0.11	-0.43	-2.57***	-2.45***	3.06***
		(1.01)	(0.21)	(0.25)	(0.17)	(0.18)	(0.28)
s	0.50***	0.48***	-0.04	0.08**	0.51***	0.49***	
	(0.07)	(0.17)	(0.04)	(0.04)	(0.07)	(0.06)	
a			-0.63***	-0.91***	-1.45***	-1.52***	-0.97***
			(0.17)	(0.18)	(0.42)	(0.34)	(0.28)
lnb		0.42***	0.04	0.05***	-0.11***	-0.1***	
		(0.05)	(0.03)	(0.02)	(0.02)	(0.02)	
f		-0.24***	-0.5***	-0.48***			0.27***
		(0.09)	(0.03)	(0.04)			(0.08)
effect	fixed	fixed	fixed	fixed	fixed	fixed	fixed
Ob.	162	162	350	350	189	189	134
ad.R^2	0.27	0.46	0.50	0.46	0.72	0.73	0.76
D.W.	1.97	2.21	2.30	1.94	1.97	2.25	2.36

Second, this paper has analyzed the heterogeneous effects among different regions. Using clustering analysis method and according to the added value per unit of pesticide application in regions, 31 provinces and cities are divided into four categories: low efficiency regions such as Shanxi, Jilin, Anhui, Jiangxi, Hunan and Gansu, high-medium efficiency regions such as Tianjin, Hebei, Liaoning, Jiangsu, Chongqing, Sichuan and Xinjiang, and high efficiency regions such as Guizhou, Tibet, Shaanxi, Qinghai and Ningxia, the remaining 13 provinces and cities are low-medium efficiency regions.

The R&D investment imposes the highest positive effect on low efficiency areas, followed by medium and high efficiency areas, and the lowest positive effect on low-medium efficiency areas. The proportion of agricultural labor force above college education has the biggest positive impact on low efficiency areas, followed by medium-high efficiency areas, which have little impact on low-medium efficiency areas and have no significant impact on high efficiency areas. However, the cross term of R&D investment and human capital has strong negative effect on low efficiency areas, strong negative effect on medium-high efficiency areas, low negative impact on low-medium efficiency areas, and no significant impact on high efficiency areas.

Agricultural machinery power has a weak positive impact on low efficiency areas and low-medium efficiency areas, but non-significant impact on medium-high efficiency areas, and show a negative impact on the high efficiency areas. Fiscal spending on agriculture has a weak and positive impact on all regions. The intensity of fertilizer application has a positive effect on high efficiency areas, but a negative effect on the other three types of regions. Disaster rate has a significant negative effect on all four regions. The operation intensive degree and cultivated land scale impose different effects on different regions. The multiple-crop index has a negative effect on low efficiency areas and low-medium efficiency areas, and has positive effect on high efficiency areas, and has non significant effect on high-medium efficiency areas.

4 | RESULTS ANALYSIS

By analyzing the influence factors of pesticide application efficiency in China, the main results are concluded as follows:

The amount of pesticide application in China has increased, but the output efficiency of the added value per unit of pesticide application is becoming higher. From 1990 to 2020, the total pesticide application in China has increased by 1.79 times from 733,000 tons to 1,313,000 tons. However, the added value of AFHF has increased by 5.71 times from 1990 to 2020 and 4.67 times at the price in 1990, so the output efficiency per unit of pesticide has increased by 3.19 times and 2.61 times, respectively.

The amount of pesticide application and output efficiency of added value per unit of pesticide application vary greatly between provinces and cities. Between 1991 and 2018, the total application of pesticides has decreased only in 6 of 31 provinces, but that in other regions has increased. The pesticide application per unit of planting area has decreased only in Shanghai and Qinghai. But the output added value of AF per unit of pesticide application has decreased only in Inner Mongolia, Jilin, Heilongjiang and Gansu, while the output added value of AF per unit of pesticide application has increased positively in the other 27 provinces and cities.

There are significant gaps of R&D investment and employment in agricultural labor force between regions. During recent years, the ratio of R&D investment to GDP is more than 2% only in Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Shandong, Guangdong and Shaanxi, but it is yet low in other regions. The proportion of agricultural labor force receiving college education or above is over 5% of college education only in Beijing, Shanghai, Zhejiang, Fujian, Shandong and Shaanxi, which is very low in other regions.

Empirical analysis show that: (a) The intensity of R&D investment and the proportion of agricultural labor force with college education or above have a positive impact on the added value growth per unit pesticide, but the intersection of the two has a negative effect on the added value growth per unit pesticide use. (b) The R&D investment intensity and the proportion of high-quality labor force in low-efficiency areas are both low, but their influence coefficients are the largest. (c) The added value output per unit of pesticide application is mostly in large and sparsely populated regions, where the R&D investment intensity is low but its effect is high. Due to the low proportion of high-quality agricultural labor force in these regions, its impact is not significant. (d) The proportion of financial support for agriculture has a positive impact on the output added value per unit of pesticide in all regions, while the disaster rate shows negative effect; the intensive degree of agricultural operation has positive impacts on all regions. Except of high efficiency areas, the intensity of fertilizer application has negative effects on other types of regions.

5 | CONCLUSION

Pesticides are important materials for agricultural production, which has an indispensable role in preventing diseases and insect pests, promoting production and improving crop yield, but it inevitably causes product and environmental pollution. The green development is the fundamental way of high-quality and efficient agricultural development, which need reduce the use of pesticides. The effective measures to improve the output efficiency of pesticide use based on the analysis results are the followings:

First, the agricultural enterprises should strengthen the integration of R&D investment and the quality of agricultural labor force, and promote green agricultural development and the efficiency of pesticide application. Investment in agricultural science and technology increases the agricultural output efficiency and agricultural product quality, improves the quality of pesticides, perfects the pesticide application methods and innovates the comprehensive pest control methods, so as to greatly increase the output added value of pesticide application. Only by improving the quality of agricultural labor force and strengthening the training of agricultural science and technology, changing the current confusion of insufficient combination of agricultural science and technology and agricultural labor force, and promoting the integration of the two can we build a virtuous cycle of agricultural science and technology innovation and agricultural labor force quality improvement.

Second, the agricultural land transfer system needs to be reformed effectively to realize the moderately intensive operation scale of agricultural entities, which needs the governments reform the land policy. The study has found that reasonable intensive degree has positive impact on the added value per unit of pesticide application, which encourages agricultural farmland amassing to high-quality agricultural operators, extends the application of agricultural science and technology, accelerates the process of agricultural modernization, raises the output efficiency of the added value of pesticide application, and speeds up the green development of agriculture.

Third, the financial measures should be perfected to support agriculture and enhance the adjustment function of policy leverage, which requires related departments and institutes formulate precise industrial policies. Stable development of agriculture is the basic state policy, and the strategic goal of high-quality agricultural development is for rural revitalization in China. Local governments need to continuously consummate their fiscal agricultural support policies according to the actual agricultural conditions so as to stabilize agricultural production, promote the rational flow of agricultural resources, and promote the green upgrading and efficient development of the agricultural industry.

Fourth, the local governments must strengthen the construction of agricultural infrastructure and encourage the cultivation of superior breeds that enhances the ability of agricultural operations resisting disasters to reduce the disaster rate. The disaster rate greatly reduces the added value output of pesticide application, increases the agricultural operation cost and reduces the agricultural income. That strengthening the construction of disaster resistance infrastructure, and cultivating efficient breeds preventing disaster and insect, can effectively reduce the amount of pesticide application and increase the added value output per unit pesticide application.

Finally, the institutes of agricultural R&D require increasing the scientific and technological research on fertilizer quality and application methods. The fertilizer application intensity is too big in most parts in China. As the application of pesticide grows too fast, farmland fertility degrades so that the output capacity decreases year by year, and the cost of agricultural production materials are rising rapidly, which leads to the negative impact on agricultural output efficiency. It is necessary to strengthen the scientific research of soil fertility improvement, realize comprehensive application of inorganic and organic fertilizer, adopt the integration of pesticide control and biological pest control, which reduces the application of pesticide and fertilizer, and improves the crop output efficiency of green planting.

DISCLOSURE STATEMENT

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