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How Does Agricultural Green Transformation Improve Residents' Health? Empirical Evidence from China

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Abstract: Promoting green and sustainable agriculture is of great significance for ensuring food security and addressing global challenges. Meanwhile, health has increasingly become a global concern. Nutrition and health are the purpose of agricultural production. As two major global issues, how agriculture empowers human health has long been discussed. Based on the provincial panel data of China from 2003 to 2021, this paper studies the impact of agricultural green transformation (AGT) on residents' health and explores its impact mechanism. The empirical results show that: (1) AGT in China has significantly reduced the average mortality rate and maternal mortality rate and significantly increased the average life expectancy, indicating that AGT in China has significantly improved the health level. The conclusions of robustness testing methods such as replacing AGT indicators and controlling endogeneity are still valid; and (2) The impact of AGT on residents' health depends on the regional economic level, and there is a threshold effect. Compared with low-income areas, the positive effects of AGT in high-income areas on residents' health are more pronounced; and (3) Agricultural carbon emissions play an intermediary effect between AGT and residents' health, and AGT can improve residents' health by reducing carbon emissions. The level of local education development plays a moderating role in the relationship between AGT and residents' health. Agricultural policy implications include enhancing the ability to protect and utilize agricultural resources, promoting the green and low-carbon transformation of agriculture, and taking a more scientific and systematic approach towards the complex diversity of health risk factors.

Keywords: agricultural sustainability; agricultural green transformation (AGT); health; agricultural policy

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1. Introduction

Promoting the green and sustainable transformation of agriculture and ensuring food security is an important issue for global peace and development [1]. Agricultural development has brought unprecedented growth in global food supply, but extensive practices have also led to serious damage to nutritional security and the environment [2]. In traditional farm management, the misuse of synthetic pesticides not only damages the environment but also leads to pesticide residues entering the food chain, affecting human health [3]. For these reasons, green agriculture has become more and more popular in recent years. The agricultural green transformation (AGT) refers to the shift from traditional agricultural production models to green, efficient, and sustainable development models [4]. Thus, AGT can improve soil quality, reduce carbon emissions, and improve food security [5,6]. All these are thought to be beneficial to human health, which has also increasingly become a global issue [7]. Scholars and experts have argued that future pandemics and epidemics are inevitable, and the problem is not whether they will occur, but when a new health emergency will emerge [8]. Agriculture is a key carrier connecting

natural systems and human health. As two major global issues, how agriculture empowers human health has long been a topic of discussion [9].

China is one of the oldest agricultural countries in the world, having 9% of the world's arable land and 18% of the world's population [10]. AGT in China is conducive to promoting the green development of world agriculture and is of great significance to global climate change and sustainable development. Since the 21st century, the resource-saving and environmentally friendly agricultural production system of China has made significant achievements. Meanwhile, the health of the Chinese people has improved significantly. According to the Statistical Bulletin on the Development of China's Health Service in 2021, life expectancy in China has risen from 71.4 years to 77.93 years from 2003 to 2021. The maternal mortality rate has been reduced from 47.8 per 100,000 to 16.1 per 100,000 and the infant mortality rate has dropped to 5.0. The key health indicators are among the highest in middle- and high-income countries. As the cornerstone of healthy nutrition, does AGT play a role in promoting national health in China? How much is the effect? How are they connected? Understanding this problem is helpful to make clear the direction of AGT in China, improve people's health level, and realize the harmonious development of man and nature.

The impact of agriculture on ecosystems and health has long been a focus of academic discussion [11]. Some researchers thought health could be put on more sustainable and healthier production patterns and lifestyles. Strengthening the links between health outcomes and agricultural research has been an urgent issue [12,13].

In general, there are three main sources of health hazards from traditional agriculture. The first is the environmental pollution caused by industrial agriculture, which is often detrimental to soil health [14,15]. Contaminants are moved from industrial waste to farmland, plants, and livestock, harming human health through the food chain [16–18]. The second is the traditional agricultural production methods. In traditional agriculture, farm productivity was directly proportional to the use of agrochemicals [19]. Improper and unsafe use of these agrochemicals, especially pesticides, was not only harmful to the environment but also to human health [20,21]. Moreover, poor recycling of animal waste in the livestock sector contributed to water pollution [22,23]. The polluted work environment also harmed the health of practitioners. Studies have shown that respiratory diseases associated with agriculture were one of the main occupational hazards [24,25]. The third is micronutrient malnutrition and stunting caused by agricultural models. Certain changes in crop production systems could have a significant impact on the growing problem of micronutrient malnutrition or hidden hunger [5]. The prevalence of micronutrient deficiency has become more common in recent years. The rate of micronutrient reduction has further been increased by the perpetual demands of modern crop cultivars: high soil erosion [26]. Studies have stated that the introduction of modern wheat and rice production methods is associated with a time trend in the increase in iron deficiency anemia in non-pregnant women [5]. The micronutrient deficiency could be a remarkable risk for future agricultural transformation [27].

Considering the negative effects of traditional farming, some researchers believe that green agricultural systems should be made to improve health. So far, numerous studies have focused on the green development of agriculture itself, especially with respect to its evaluation and calculation [28–30]. As for its impact on health, there is still much debate in the academic community. Some scholars believe that the green revolution in agriculture is beneficial to health. Residues in conventional fruits and vegetables constitute the main source of human pesticide exposures, while the use of pesticides is restricted in green agriculture [31,32]. Green agriculture uses fewer chemicals, reduces environmental hazards, and helps to ensure a more sustainable future for agriculture [33]. Moreover, the consumption of organic food reduces the risk of allergic diseases, being overweight, and having obesity. Consumers of organic food generally tend to have healthier lifestyles overall [34,35]. However, other studies have suggested that the green revolution in agriculture has not been improved. They argue that some of the interventions deviate from the natural laws

of balance and functioning and are unsustainable practices [34]. Organic amendments to agricultural soil often contain a range of pollutants, including persistent organic pollutants, potential human pathogens, which entail a variety of risks for environmental and human health [35].

Although existing studies have provided rich insights into understanding the relationship between agriculture and health, more efforts are still needed to account for the relationship between the two. First, regarding the relationship between agriculture and health, studies have mostly focused on the impact of the traditional agriculture model on health, while the impact of AGT on health has rarely been studied. Second, there is insufficient attention in existing research on the mechanism of the impact of AGT on health. Is there any other channel for the impact of AGT on health besides its direct impact on residents' health? Third, health itself is a medical field, but it is also constrained by socio-economic factors. Are there any links between economic factors such as economic development and education and the health effects of AGT in China? What role do they play in this process? These issues are worth further exploration in the context of China's agricultural green transformation.

The contribution of this study is as follows: (1) This article provides an economic explanation for the impact of AGT on health, which enriches current research on public health in China and provides insights for understanding the relationship between agriculture and health. (2) The direct and indirect effects of AGT on health have been demonstrated from both theoretical and empirical perspectives, conducive to a more comprehensive understanding of the impact of AGT on health. (3) The threshold effect test is used to investigate the role of economic development in the effects of AGT on health in China, providing a perspective for understanding the role of socio-economic factors on resident health.

The remainder of this paper is as follows. In Section 2, we elaborate the theoretical mechanism of the impact of AGT on residents' health. Section 3 first introduces the method of empirical analysis and then defines the relevant variables. Section 4 carries out the empirical analysis. Section 5 is the conclusion, featuring some policy implications.

2. Theoretical Mechanism Analysis

We build a theoretical framework to analyze the theoretical mechanism of the impact of AGT on residents' health. The green transformation of agriculture has an impact on residents' health through both direct and indirect channels.

Direct channel: AGT emphasizes the conservation of agricultural resources and ecological protection, promotes the greening of agricultural production processes, enhances the nutritional value of food, and benefits the physical and mental health of consumers.

Indirect channels: AGT has an indirect impact on residents' health by reducing agricultural carbon emissions and environmental pollution. In addition, the higher the level of local education development, the higher the quality of rural human capital, which is of great significance for the impact of AGT on residents' health.

Carbon emissions do harm to people's health. As greenhouse gases like carbon dioxide increase, so do pollutants in the air. According to Global Burden of Disease (GBD) estimates, environmental pollution-related diseases caused 9 million premature deaths in 2015, accounting for 16 percent of total global deaths. Pollution-related diseases accounted for 268 million disability-adjusted life years. Pollution kills three times as many people as AIDS, tuberculosis, and malaria combined [36].

Agriculture is a major source of carbon emissions. In China, with the green process of agriculture, the adjustment of planting structure, and the promotion of organic fertilizers, the use of pesticides and fertilizers has been decreasing. According to the *China Agricultural Green Development Report 2022*, the amount of agricultural chemical fertilizer applied in China was 51.91 million tons in 2021, 13.8 percent lower than in 2015, and the amount of pesticide used was 248,000 tons in 2021, 16.8 percent lower than in 2015. The green transformation of agriculture is conducive to improving the quality, efficiency, and competitiveness

of agriculture, cultivating green and low-carbon production lifestyles, thus improving the health level of residents. Therefore, this paper proposes the following hypothesis:

Hypothesis 1. *AGT can improve residents' health by reducing agricultural carbon emissions. Therefore, agricultural carbon emissions play a mediating role between agricultural green transformation and residents' health.*

Through the influence of AGT on residents' health, the regulating effect of education development should be fully considered. From the perspective of agricultural production, the higher the level of education, the higher the quality of rural human capital. Rural human capital can improve the innovation ability and adaptability of agricultural producers, promote the promotion of agricultural green technology, promote the progress of agricultural science and technology, and effectively improve the efficiency and quality of agricultural production. From the perspective of consumers, the higher the level of education, the more consumers are inclined to accept green products and healthy lifestyles.

Therefore, this paper proposes the following hypothesis:

Hypothesis 2. *The level of education development moderates the impact of AGT on residents' health. The higher the level of local education development, the greater the positive effect of AGT on health.*

3. Methodology

3.1. Method

3.1.1. Fixed-Effects Model

The Hausman test is a common method for testing the choice between the random-effects model and the fixed-effects model. The Hausman test results show that the *p*-value is less than 0.01. It means that the original hypothesis has been rejected. Therefore, the fixed-effect model is adopted in this paper. The following benchmark model was constructed with AGT as the core explanatory variable and health as the explained variable:

$$\ln Health_{jit} = \beta_0 + \beta_1 \ln AGT_{it} + \beta_2 X_{it} + \mu_{it} + \varepsilon_{it} \quad (1)$$

where i denotes the variable in region I and t represents the year in the sample period. $\ln AGT_{it}$ denotes the agricultural green transformation. $\ln Health_{jit}$ represents residents' health. It represents the average life expectancy when $j = 1$, average death rate when $j = 2$, and mortality rate when $j = 3$. X_{it} is the control variable. μ_{it} is the individual fixed effects. ε_{it} is a disturbance term that varies with provinces and time.

3.1.2. Threshold Effect

Is there any difference in the impact of AGT on residents' health in regions with different economic levels? To answer this question, we build an income threshold model of economic development on residents' health based on Hansen (1999) [37]:

$$\begin{aligned} \ln Health_{jit} = {} & \alpha + \beta_1 GDP_{it} \times I(\ln AGT_{it} \le \gamma_1) + \beta_2 GDP_{it} \times I(\gamma_1 < \ln AGT_{it} \le \gamma_2) + \ldots \\ & + \beta_n GDP_{it} \times I(\gamma_{n-1} < \ln AGT_{it} \le \gamma_n) + \beta_{n+1} GDP_{it} \times I(\ln AGT_{it} > \gamma_n) + \theta X_{it} + \varepsilon_{it} \end{aligned} \quad (2)$$

where i denotes the variable in region I and t represents the year in the sample period. GDP_{it} denotes the economic development. $\ln AGT_{it}$ denotes the agricultural green transformation. $\ln Health_{jit}$ represents residents' health. It represents the average life expectancy when $j = 1$, average death rate when $j = 2$, and mortality rate when $j = 3$. X_{it} is the control variable. μ_{it} is the individual fixed effects. ε_{it} is a disturbance term that varies with provinces and time.

3.1.3. Mediation Effect

This paper takes agricultural carbon emission (C_{it}) as the mediation variable. If AGT has an impact on residents' health by reducing carbon emission, then agricultural carbon

emission is the mediation variable of AGT and residents' health. The purpose of this study is to explore the mechanism of the relationship between AGT and residents' health.

$$C_{it} = \alpha_0 + \alpha_1 \ln AGT_{it} + \alpha_2 X_{it} + \varepsilon_{it} \quad (3)$$

$$\ln Health_{jit} = \alpha_0 + \alpha_1 C_{it} + \alpha_2 X_{it} + \varepsilon_{it} \quad (4)$$

$$\ln Health_{jit} = \alpha_0 + \alpha_1 \ln AGT_{it} + \alpha_2 C_{it} + \alpha_3 X_{it} + \varepsilon_{it} \quad (5)$$

where i denotes the variable in region I and t represents the year in the sample period. ln AGT_{it} denotes the agricultural green transformation. C_{it} represents agricultural carbon emission. ln $Health_{jit}$ represents residents' health. It represents the average life expectancy when j = 1, average death rate when j = 2, and mortality rate when j = 3. X_{it} is the control variable. μ_{it} is the individual fixed effects. ε_{it} is a disturbance term that varies with provinces and time.

3.1.4. Moderation Effect

According to the above analysis, education is another transmission mechanism of the health impact of green transformation in agriculture. Unlike agricultural carbon emissions, education plays more of a regulatory role. Therefore, this paper takes education level as a moderating variable and builds the measurement model as follows:

$$\ln Health_{jit} = \beta_0 + \beta_1 AGT_{it} \times Edu_{it} + \beta_2 AGT_{it} + \beta_3 Edu_{it} + \beta_4 X_{it} + \varepsilon_{it} \quad (6)$$

where i denotes the variable in region I and t represents the year in the sample period. ln AGT_{it} denotes the agricultural green transformation. ln $Health_{jit}$ represents residents' health. It represents the average life expectancy when j = 1, average death rate when j = 2, and mortality rate when j = 3. Edu_{it} is the local education level. X_{it} is the control variable. μ_{it} is the individual fixed effects. ε_{it} is a disturbance term that varies with provinces and time. ln $AGT_{it} \times Edu_{it}$ represents the interaction term between the agricultural green transformation index and education level. If the regression coefficient is positive, it indicates that the health of residents is promoted through the moderation effect of local education development level and vice versa.

3.2. Variable

Explained variable (Health): The main health indicators of China's general health development goal include average life expectancy, infant mortality rate, and maternal mortality rate. Average life expectancy is a metric to measure national health and happiness, which ranks first in the three core indicators of the United Nations Human Development Index. In addition, the increase in the average life expectancy of the population is the result of the combined effect of the decline in mortality rates at all ages, in which the decline in infant mortality and maternal mortality play a crucial role as a "thermometer" of the health level of a country. In this paper, we use the average life expectancy ($health_1$), average death rate ($health_2$), and mortality rate ($health_3$) to represent the health level of the population.

Explanatory variables (AGT): Agricultural green transformation refers to the transformation of agriculture from traditional production models to green, efficient, and sustainable development models with the goal of protecting the ecological environment and promoting sustainable development. It emphasizes minimizing the negative impact on the environment in the process of agricultural production, improving the efficiency of resource use and protecting the stability and health of the ecosystem. Based on Yao and Li (2023) [38], this paper constructs an agricultural green development level index system from three dimensions: agricultural resource conservation, agricultural environmental governance, and agricultural production.

Agricultural resource conservation refers to the economical use of natural resources in the process of agricultural production. Agricultural environmental control refers to the control of environmental pollution in the process of agricultural production. Agricultural

production efficiency indicates agricultural production and income. In this paper, the weight of each three-level index is determined by the entropy weight method. The basic idea of the entropy weight method is to determine the objective weight according to the variation degree of the index value. In index processing, three-level index values are normalized by range processing, and dimensionless data with the same direction influence and comparability are obtained. The two-level index value is obtained by weighted summing of the three-level index value, and then the two-level index value is obtained by summing up the agricultural green development level of each region. The weights of indicators at all levels obtained by this method are shown in Table 1.

Table 1. Agricultural green transformation index system.

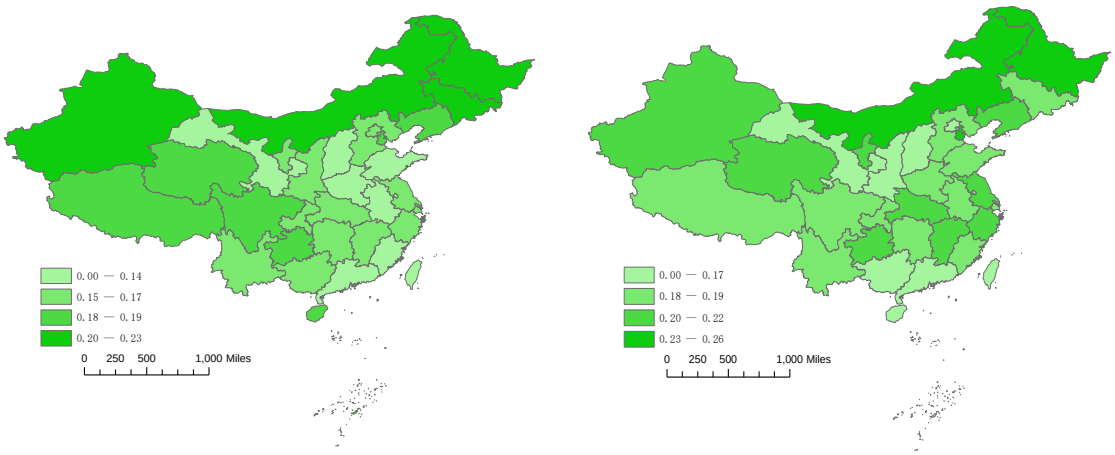
Secondary Index	Three-Level Index	Meaning and Unit of the Indicator	Indicator Direction
Agricultural resource conservation	Arable land per capita	Arable land/Total population (ha/person)	+
	Multiple cropping index of cultivated land	Total sown area/Cultivated area of crops	−
	Proportion of effective irrigated area	Available irrigated area/Cultivated area	+
Agricultural environmental control	Pesticide use per unit sown area	Pesticide use/Total sown area (kg/ha)	−
	Fertilizer use per unit sown area	Fertilizer application amount/Total planted area of crops (kg/ha)	−
	Machinery input per unit of agricultural output value	Total power of agricultural machinery/Total agricultural output value (kW/CNY 1 million)	−
	Amount of agricultural film per unit of agricultural output value	Agricultural film usage/Total agricultural output value (kg/CNY 10,000)	−
Agricultural production efficiency	Per capita agricultural output value	Total agricultural output value/Total number of agricultural employment (CNY 10,000/person)	+
	Per capita net operating income of rural residents	Average net income level of rural residents from business activities (CNY/person)	+

Figure 1 shows the AGT values determined by the entropy weight method in 2003 and 2021. As is shown in Figure 1, the level of AGT in China has significantly improved from 2003 to 2021, especially in the eastern coastal areas. For example, AGT in Jiangsu has increased from 16.5 percent to 21.3 percent, and in Zhejiang, it has increased from 16.4 percent to 22 percent. Improvements were also evident in the west. For example, Yunnan Province increased from 16.4 percent to 18.5 percent, and Qinghai Province increased from 17.7 percent to 20.6 percent.

Mediation variable: We take agricultural carbon emissions (C) as the mediation variable. As there is no actual data of agricultural carbon emission, the carbon emission formula of agricultural production is constructed based on the carbon emission estimation methods of Wen et al. (2022) [39].

$$C = \sum C_m = \sum (T_m \times \delta_m) \quad (7)$$

where C is the total carbon emissions from agricultural production, C_m is the carbon emissions from various carbon sources, T_m is the amount of each carbon emission source, and δ_m is the carbon emission coefficient of each carbon emission source. According to the characteristics of the carbon emission source of agricultural production, this paper determined the specific carbon source factor and its corresponding carbon emission coefficient from three aspects: agricultural materials, soil, and rice field.



(**a**) (**b**)

Figure 1. Distribution maps of the AGT of China: (**a**) 2003; (**b**) 2021.

Moderation variable: We take education level (*Edu*) as the moderation variable. In this paper, it is expressed by the average number of students in higher education institutions in each province.

Control Variables

Economic development (*GDP*). The development of the economy will bring about the improvement of living conditions, which will benefit the health of the residents. Economic development also increases investment in healthcare, which in turn improves the level of medical services and disease prevention. At the same time, economic development may be accompanied by environmental pollution, lifestyle changes, and an increase in chronic non-communicable diseases such as cardiovascular and cerebrovascular diseases, all of which have a negative impact on health. The economic development in this paper is expressed by the per capita GDP of each province.

Degree of aging (*Old*). The aging process in China continues to accelerate. Older people have a higher risk of chronic diseases and are more vulnerable to environmental impacts on health. The degree of aging is measured by the proportion of the population that is over 65 years old.

Medical care (*Medical*). Improving the medical technology ability and medical quality level is an important means to improve the health level of residents. The medical care in this paper is expressed in terms of health technicians per 1000 people.

Social security (*Insurance*). Medical security is an important part of social security and a key way for people to obtain health services. Medical security can ensure that residents have access to certain medical services and receive effective treatment and rehabilitation support. The social security in this paper is expressed by the number of people on medical insurance.

Industrial structure (*Is*). The development of the tertiary industry is conducive to improving the ecological environment; especially, the development of the health industry is conducive to improving the health level of residents. The industrial structure in this paper is expressed by the proportion of tertiary industry. In order to avoid heteroscedasticity, this paper enlarges AGT by 100 times and takes the logarithm of it. The variables are shown in Table 2.

Table 2. Variable description.

Variable	Unit	Obs	Mean	Std. Dev.	Min	Max
ln *AGT*		589	2.92	0.14	2.54	3.34
$Health_1$	year	589	74.89	3.69	64.37	82.55
$Health_2$	per 100,000	589	6.07	0.80	4.21	8.89
$Health_3$	per 100,000	589	27.13	37.70	1.10	401.40
ln *GDP*	CNY	589	10.40	0.76	8.19	12.12
Old		589	0.10	0.02	0.05	0.19
Medical	per 1000 people	589	5.43	2.08	1.79	15.46
ln *Insurance*	10,000 people	589	6.43	1.13	1.49	8.59
IS	%	589	44.41	9.71	28.60	83.90
ln *C*		589	5.73	1.26	2.10	7.24
ln *Edu*	people	589	7.68	0.43	6.21	8.84

3.3. Data Source

The sample used includes 31 provinces (municipalities) in China from 2003 to 2021. The data are derived from the *China Statistical Yearbook* (2004–2022), *China Health Statistics Yearbook* (2004–2022), and *China Environmental Statistics Yearbook* (2004–2022).

4. Results

4.1. Fixed Regression Result

Table 3 shows the regression results of the effects of AGT on the average life expectancy, mortality rate, and maternal mortality rate. Columns (1), (3), (5), and (7) are listed as the effects of the agricultural green transformation index on health when control variables are introduced without considering the provincial effect. Columns (2), (4), (6), and (8) are listed as the effects of the agricultural green transformation index on health when control variables are introduced and the provincial effect is controlled. We take life expectancy as the health indicator as an example. Without controlling for time effects and province effects, the influence coefficient of agriculture green transformation on life expectancy is 0.0703, significant at the 5% level. Controlling for the time effect and province effect, the influence coefficient of agricultural green transformation on life expectancy is 2.185, significant at the 1% level. This indicates that AGT has significantly increased the average life expectancy. When using the average death rate as a health indicator, the influence coefficient of agriculture green transformation is −0.935 without controlling for the time effect and province effect, significant at the 1% level. The influence coefficient is −0.786 when controlling for the time effect and province effect. This indicates that AGT has significantly reduced the average death rate. The conclusion is the same for maternal mortality rate. In conclusion, AGT in China has presented a typical positive correlation with health.

Table 3. Fixed regression result.

	(1)	(2)	(3)	(4)	(5)	(6)
	$Health_1$	$Health_1$	$Health_2$	$Health_2$	$Health_3$	$Health_3$
ln *AGT*	0.0703 **	2.185 ***	−0.935 ***	−0.786 **	−0.331 **	−0.22 **
	(0.7755)	(0.3214)	(0.2782)	(0.2878)	(0.2046)	(0.2192)
ln *GDP*	2.783 ***	1.721 ***	−0.0232 **	−0.0821 *	−0.662 ***	−0.601 ***
	(0.2457)	(0.1637)	(0.0882)	(0.1466)	(0.0648)	(0.1116)
Old	−2.362 **	−6.852 ***	21.78 ***	20.06 ***	4.108 ***	1.833 *
	(4.2102)	(1.9367)	(1.5106)	(1.7339)	(1.1108)	(1.3206)
Medical	0.067 **	0.0189 *	0.0885 ***	0.0596 *	0.0251 *	0.0398 *
	(0.0634)	(0.0285)	(0.0227)	(0.0255)	(0.0167)	(0.0194)
ln *Insurance*	0.780 *	0.294 **	−0.357 **	−0.392 **	−0.267 **	−0.529 ***
	(0.3181)	(0.1558)	(0.1141)	(0.1395)	(0.0839)	(0.1062)

Table 3. *Cont.*

	(1)	(2)	(3)	(4)	(5)	(6)
	$Health_1$	$Health_1$	$Health_2$	$Health_2$	$Health_3$	$Health_3$
IS	0.0247	0.0115	−0.0538	−0.0266	0.22	−0.282
	(0.0131)	(0.067)	(0.047)	(0.060)	(0.034)	(0.046)
Provincial effect	NO	YES	NO	YES	NO	YES
Time effect	NO	YES	NO	YES	NO	YES
_cons	48.47 ***	56.89 ***	8.181 ***	7.752 ***	453.7 ***	507.5 ***
	(2.5662)	(1.9902)	(0.9207)	(1.7818)	(36.5291)	(68.1261)
R-sq	0.9266	0.9893	0.7992	0.817	0.9062	0.9083
N	589	589	589	589	589	589

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% significance levels. The t-values are given in the parentheses.

As for the control variables, regional economic development has a significant effect on residents' health. The coefficient of regional economic development on life expectancy is 1.721 when controlling for the time effect and province effect. This suggests that life expectancy increases as a country grows economically. Both medical care and social security have significant effects on improving life expectancy and reducing mortality. Aging increases the health risk of residents, while industrial structure has no significant effect on health.

4.2. Robustness Test

This paper conducts robustness verification from two aspects: replacing agricultural green transformation indicators and endogeneity. (To simplify the results, we only display the regression results with the average mortality rate of residents as the dependent variable).

Firstly, we use the total amount of rural biogas digesters (Biogas) and solar energy utilization (Solar) to replace the agricultural green transformation index for regression. Second, although some control variables affecting health are taken into account, there is still an endogeneity problem caused by missing variables. In addition, there may be a two-way causal relationship between AGT and health. Not only can AGT have an effect on health, but the improvement of human capital will also have a reverse effect on AGT. Therefore, we use the logarithm of the number of rural telephone users at the end of the year in each province of China (ln *Tel*) as the instrumental variable for regression. The number of rural telephone users can reflect the development of the rural information industry to a certain extent and help to improve the efficiency of the green development of agriculture. Tables 4 and 5 present the regression results using alternative agricultural green transformation indicators and the endogeneity test, respectively.

Table 4. Robustness test I: replacing indicators.

	(1) $Health_2$	(2) $Health_2$	(3) $Health_2$	(4) $Health_2$
ln *Biogas*	−0.102 ***	−0.121 ***		
	(0.282)	(0.293)		
ln *Solar*			−1.830 ***	−0.112 *
			(0.975)	(0.665)
X_{ij}	NO	YES	NO	YES
R-sq	0.6315	0.7237	0.5534	0.8497
N	589	589	589	589

Note: *** and * denote statistical significance at the 1% and 10% significance levels. The t-values are given in the parentheses.

Table 5. Robustness test II: endogeneity test.

	First Stage	Second Stage
ln *AGT*		−0.7984 ***
		(7.48)
ln *Tel*	0.0471 **	
	(9.68)	
X_{ij}	YES	YES
Cragg–Donald Wald F	96.4823 (16.38)	
K-Paap rk LM	24.7562 ***	
N	589	589
R^2	0.5266	0.6026

Note: *** and ** denote statistical significance at the 1% and 5% significance levels.

Columns (1) and (3) in Table 4 are listed as the effects of the total amount of rural biogas digesters and solar energy utilization on the average mortality rate, respectively, when control variables are not considered. Columns (2) and (4) in Table 4 are listed as the effects of the total amount of rural biogas digesters and solar energy utilization on the average mortality rate, respectively, when control variables are introduced. As can be seen, both the amount of biogas digesters and the use of solar energy in rural areas has significantly reduced the average mortality rate of the regional population. The positive effect of AGT on residents' health remained stable.

Table 5 reports the regression results of the instrumental variables. The result of the weak instrumental variable test shows that the Cragg–Donald Wald F-value is greater than the 10% critical value of Stock–Yogo, indicating that the model has passed the weak instrumental variable test. The K-Paap rk LM statistic of the identifiable test has rejected the null hypothesis at the 1% level, satisfying the identifications of instrumental variables. After considering the endogeneity, the regression coefficient of the agricultural green transmission on residents' health is still significant at the 1% level, indicating that the result of the benchmark model has a certain robustness.

4.3. Threshold Test

In order to examine whether there is a threshold effect on the relationship between AGT and health, this paper conducts a threshold effect test with reference to Hansen (1999) [37] and adopts bootstrap "self-sampling" with a sampling frequency of 300 times. Taking average life expectancy, average mortality, and maternal mortality as health indicators, the results show that there is a single threshold effect, with economic level being the threshold variable. The results are shown in Table 6. Furthermore, Table 7 shows the differences in the health impacts of AGT at different economic levels. By comparing the high economic level interval with the low economic level interval, it is found that the absolute value of the economic level coefficient is larger in the high economic level interval. It means that compared with low-income areas, the positive effects of AGT in high-income areas on resident health are more pronounced. On the one hand, it confirms that the health impact of green transformation in agriculture is limited by the economic level. On the other hand, it shows that the health of residents in low-income areas is greatly affected by the negative economic level. Factors such as insufficient health supply, psychological gaps, and environmental deterioration aggravate health vulnerability in low economic level areas.

Table 6. Threshold effect test.

Explained	Threshold	*p*	F	Crit10	Crit5	Crit1
$Health_1$	9.698	0.0000	160.38	45.8953	54.3883	61.5585
$Health_2$	10.989	0.0467	29.2	23.8762	28.8341	47.1706
$Health_3$	9.499	0.0000	84.38	24.6017	28.5426	38.141

Table 7. Threshold regression of AGT on health.

$Health_1$		$Health_2$		$Health_3$	
ln *GDP* ≤ 9.698	1.702 **	ln *GDP* ≤ 10.989	−0.964 ***	ln *GDP* ≤ 9.499	−0.303 **
	(0.7392)		(0.2563)		(0.2053)
ln *GDP* > 9.698	2.384 **	ln *GDP* > 10.989	−1.057 ***	ln *GDP* > 9.499	−0.449 **
	(0.7323)		(0.2552)		(0.2041)
X_{ij}	YES	X_{ij}	YES	X_{ij}	YES
R-sq	0.8489	R-sq	0.5463	R-sq	0.7393
X_{ij}	YES	X_{ij}	YES	X_{ij}	YES

Note: *** and ** denote statistical significance at the 1% and 5% significance levels. The t-values are given in the parentheses.

4.4. Mediation Effect Test

Table 8 shows the results of the mediation effect test. Columns (1) to (3) refer to average life expectancy as the measure of health. Columns (4) to (6) refer to the average mortality rate as the measure of health. Columns (7) to (9) refer to maternal mortality as the measure of health. According to (1) to (3), the coefficient of AGT is 0.3619, significantly positive at the 1% level. The direct effect is 0.3619. The mediation effect is 0.3408 (−0.8099 × −0.4209). This means that AGT has increased average life expectancy by lowering agricultural carbon emissions. According to the principle of mediation effect test, agricultural carbon emission plays a partial mediating role in the impact of AGT on average life expectancy. Similarly, the regression results of (4) to (6) and (7) to (9) also confirm the existence of intermediary effects. In conclusion, agricultural carbon emission is an effective way for AGT to affect residents' health. This confirms Hypothesis 1.

Table 8. Mediation effect test.

	(1) $Health_1$	(2) ln *C*	(3) $Health_1$	(4) $Health_2$	(5) ln *C*	(6) $Health_2$	(7) $Health_3$	(8) ln *C*	(9) $Health_3$
ln *AGT*	0.3799 **	−0.8099 **	0.3619 **	−0.7524 ***	−0.8099 **	−0.7049 ***	−0.2246 **	−0.8099 **	−0.2209 *
	(−0.8200)	(−2.3591)	(−0.8727)	(−4.3978)	(−2.3591)	(−4.0449)	(−1.6343)	(−2.3591)	(−1.6925)
ln *C*			−0.4209 ***			0.0591 **			0.1227 ***
			(−4.0926)			(−2.4359)			(−3.8253)
X_{ij}	YES	YES	YES	YES	YES	YES	YES	YES	YES
R-sq	0.8728	0.3281	0.8765	0.5936	0.3281	0.6	0.6596	0.3281	0.6648
N	589	589	589	589	589	589	589	589	589

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% significance levels. The t-values are given in the parentheses.

4.5. Moderation Effect Test

According to Formula 6, the test results of the moderation effect are shown in Table 9. Models (1), (3), and (5) are the test results of the moderation effect without considering the control variables. The coefficient of ln *AGT* × ln *Edu* are 1.2877, −0.2629, and −0.8398, respectively, at least significant at the 1% level. Models (2), (4), and (6) are regression results with control variables considered. The coefficient of ln *AGT* × ln *Edu* are 0.7704, −0.6820, and −0.6817, respectively, at least significant at the 1% level. All of these results mean that AGT has increased average life expectancy and reduced average mortality and maternal mortality through the moderation effect of education during the sample period in China.

In conclusion, the impact of AGT on residents' health in China is regulated by the level of education. The higher the level of regional education development, the stronger the positive impact of AGT on residents' health. This confirms Hypothesis 2.

Table 9. Moderation effect test.

	(1) $Health_1$	(2) $Health_1$	(3) $Health_2$	(4) $Health_2$	(5) $Health_3$	(6) $Health_3$
ln *AGT*	12.0444 ***	8.1695 **	−1.3506 **	−4.5468 **	−6.2048 ***	−5.1276 **
	(−3.2297)	(−2.3059)	(−0.4138)	(−1.5757)	(−2.7448)	(−2.2773)
ln *Edu*	2.4611 *	3.1016 **	−1.1979 **	−4.095 **	−2.8571 ***	−4.7682 **
	(−1.8496)	(−0.4711)	(−1.0285)	(−6.0057)	(−3.5423)	(−3.9774)
ln *AGT* × ln *Edu*	1.2877 ***	0.7704 **	−0.2629 **	−0.6820 **	−0.8398 ***	−0.6817 **
	(−2.726)	(−1.7096)	(−0.6358)	(−1.8581)	(−2.9329)	(−2.3803)
_cons	97.1421 ***	84.6214 ***	−0.9089 **	−7.8619 **	24.5502 ***	23.7176 ***
	(−9.2671)	(−8.3323)	(−0.0991)	(−0.9505)	(−3.8637)	(−3.6747)
X_{ij}	NO	YES	NO	YES	NO	YES
Time effect	YES	YES	YES	YES	YES	YES
Provincial effect	YES	YES	YES	YES	YES	YES
R-sq	0.9844	0.9885	0.7689	0.8355	0.7813	0.8921
N	589	589	589	589	589	589

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% significance levels. The t-values are given in the parentheses.

5. Conclusions

This paper uses provincial panel data to empirically test the relationship between agricultural green transformation and residents' health as well as its impact mechanism. The conclusions are as follows:

1. AGT has significantly promoted the improvement of the health level of residents in China. With average life expectancy, average mortality rate, and maternal mortality rate serving as the explained variables, the same conclusion was reached.
2. The impact of AGT on residents' health depends on the level of regional economic development with a threshold effect. Compared with low-income areas, the health of residents in high-income areas is more affected by the positive effect of AGT.
3. AGT can affect the health of local residents by affecting agricultural carbon emissions, which have an intermediary effect between AGT and residents' health. In addition, the regional education level moderated the relationship between AGT and residents' health.

Based on the conclusion, we propose the following agricultural policy implications:

1. Promote the green transformation of agriculture: We should enhance the ability to protect and utilize agricultural resources and enhance the utilization rate of water resources; strengthen environmental protection in the agricultural industry and promote the reduction of chemical fertilizers and pesticides to increase efficiency; and improve the supply quality of green and high-quality agricultural products and drive the high-quality development of agriculture.
2. Reasonable measures should be taken to reduce carbon emission: Emission reduction in agriculture is an important part of China's carbon peak. We should increase the carbon sequestration of agricultural soil by using farm manure instead of chemical fertilizer; optimize the breeding structure, promote the combination of breeding and ecological health breeding technology, and improve the treatment rate and return rate of livestock and poultry manure; and develop the rural biomass energy industry, utilize waste resources to develop biomass energy, and continue to promote the green and low-carbon transformation of agriculture and high-quality development in rural areas.
3. Strengthen the publicity of the relationship between agricultural green transmission and residents' health: According to our conclusion, the green development of agriculture has positive significance for improving residents' health. However, residents' understanding of the relationship is still incomplete. Therefore, it is necessary to popularize the publicity of the effects of rational fertilization, reducing the use of pes-

ticides and improving the use efficiency of cultivated land on the health of residents. Then, the residents would consciously integrate the concept of green agricultural development into their daily lives and ultimately achieve the virtuous cycle of the relationship between green development and residents' health.

4. Take more scientific and systematic measures to continuously improve the health of the people: The impact of agricultural green transformation on health is restricted by economic level, education level, and economic and social factors such as population aging and medical security. The complexity and diversity of health risk factors, including biological, physical, and social environment; health services; individual behavior and lifestyle factors; and the increasing trend of population aging, require more comprehensive and systematic measures to improve health. Government investment should lean towards medical and health services, and the supply of quality health products and services should be continuously increased. We should improve the implementation mechanism and guarantee mechanism of giving priority to health.

Regarding the selection of indicators, there are various methods to measure AGT. Future research could consider factors such as digital agriculture, smart agriculture, and the new quality of agricultural productivity. Due to the limitation of data availability, the agriculture carbon emissions are estimated from three aspects, including agricultural materials, soil, and rice fields. This may influence the conclusion to some extent. In addition, this paper has adopted the provincial level as the scale of spatial analysis. Smaller scales, such as the county-level units, could be considered in future research.

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