

Analysis of the impact of farmland transfer on agricultural carbon emissions – Based on survey data from farming households in groundwater irrigation areas of Hebei Province, China

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Abstract: Farmland transfer is a practical need for China to achieve agricultural mechanisation and modernisation, and also an important way for farmers to optimise their family resource allocation. The existing studies ignore the impact of farmland transfer on the environment, especially carbon emissions. The practical significance of this paper lies in exploring the likely mechanisms driving the effect of the farmland transfer on agricultural carbon emissions from a microeconomic perspective using data from rural households, based on the heterogeneity of land management scale. Results show: (i) Land transfer impacts carbon emissions differently. Land transfer of small-scale farmers increases carbon emissions, while large-scale farmers reduce them. The threshold value of land management scale is 1 ha. (ii) The impact mechanisms are water-saving technology adoption and input of fertilizers and pesticides. Small-scale farmers increase fertiliser and pesticide input after land transfer, increasing carbon emissions. Large-scale farmers mostly reduce irrigation electricity consumption, as well as fertilizer and pesticide input, thus reducing agricultural carbon emissions. Conclusion: It is recommended to guide farmers to expand farmland transfer scale through subsidy policies; guide small-scale farmers' green agricultural production behaviours; and increase the adoption rate of water-saving technologies.

Keywords: agricultural land transfer; carbon emissions; land management scale; water-saving technology

Carbon emissions from the global agricultural sector account for about 21% to 37% of the global total carbon emissions (Rosenzweig et al. 2020). Agriculture is one of the important sources of carbon emissions (Fan et al. 2020). To respond to climate change, China proposed the 'dual carbon' goal at the 75th United Nations General Assembly and elevated it to a national strategy. In terms of agricultural carbon emission reduction, the '14th Five-Year Plan for Promoting Agricultural and Rural Modernisation' clearly proposes

to 'promote agricultural and rural emission reduction and carbon fixation' (The State Council of China 2021). Therefore, how to promote agricultural carbon reduction will be one of the important contents of future agricultural green development, and research on agricultural carbon emissions has practical significance. As the focus of academic research, agricultural carbon emissions are rich in related achievements. On the one hand, scholars have discussed the measurement of agricultural carbon emissions and further explored the

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regional differences in agricultural carbon emission intensity in temporal and spatial distribution (Lin and Fei 2015; Wu et al. 2018). On the other hand, scholars have deeply analysed the impacts of agricultural economic development (Yao et al. 2024), agricultural industrial agglomeration (Wu et al. 2018), technological development (Churchill et al. 2019) and environmental regulation (George et al. 2017; Li et al. 2023) on agricultural carbon emission and intensity.

In recent years, farmland transfer in China has shown a gradual increase. The realisation of scale management through agricultural land transfer is a meaningful way to realise the marketisation of small farmers and agricultural modernisation (Rogers et al. 2021). Agricultural carbon emissions are the negative effect of agricultural activities on the environment, which is closely related to agricultural development and is bound to be impacted by agricultural land transfer. Therefore, when analysing the influencing factors of agricultural carbon emissions, we need to consider the impact of land transfer. At present, academic research on farmland transfer is mostly focused on its social and economic effects. For example, farmland transfer will have an impact on the scale of agricultural operations, agricultural labour transfer, agricultural production efficiency and farmers' income (Liu et al. 2017; Cheng et al. 2019; Liu et al. 2019; Kijima and Tabetando 2020). The farmland transfer not only affects economic efficiency but also has an impact on the environment, but research about this topic is rarely. Relevant literature mainly focuses on its influence on agricultural non-point source pollution and fertiliser use (Lu and Xie 2018; Mugizi 2022; Séogo and Zahonogo 2023). Research on agricultural carbon emissions mostly relies on macro-statistical data (Tang and Chen 2022; Liao et al. 2023; Li et al. 2024; Quan et al. 2024), lacking studies at the farmer household level.

This paper aims to expand the existing literature from the following aspects: (i) By analysing the impact and mechanism of agricultural land transfer on agricultural carbon emissions, clarifying the relationship between them, and exploring its possible impact on the environment, not just paying attention to economic benefits. (ii) Small-scale farmers are an important subject of China's agricultural production (Hou et al. 2021). This paper takes farmers' production input behaviour as the research objective, and pays attention to individual farmers' carbon emissions in agricultural production process. In summary, this study goes beyond the prevailing focus on the economic outcomes of land

transfer by exploring its potential environmental impacts, thereby offering a new approach to advancing sustainable development goals. This farmers-level perspective provides valuable empirical support for promoting land transfer and the development of low-carbon agriculture in China, contributing a Chinese case study and practical insights toward achieving sustainable development and implementing emission reduction efforts in the agricultural sector.

Literature review. The agricultural land transfer affects the agricultural sector's economic efficiency by promoting appropriate scale agricultural operations, enhancing agricultural mechanisation, improving the utilisation efficiency of agricultural land, and increasing agricultural productivity (Yan et al. 2019; Yu et al. 2022). The most direct impact of land transfer is the expansion of farmers' land management scale. Changes in land resource endowment will inevitably affect farmland input (Li et al. 2022). So, agricultural land transfer also has an impact on the environment at the same time. For example, the improvement of agricultural mechanisation levels will lead to an increase in energy consumption (Lu et al. 2019), resulting in higher agricultural carbon emissions. Another example is that in order to make up for the transfer rent, farmers may increase the planting area of cash crops or switch to high-yield crops (Tan et al. 2023). These crops usually require more chemical fertilisers and pesticides, thus increasing the carbon emissions released in the form of agricultural production materials.

The academic community has discussed the impact of land transfer on carbon emissions but has not yet reached a unified view (Cheng et al. 2023). Some scholars have studied the long-term and short-term impacts of land transfer on agricultural production, the results suggest that land transfer will increase carbon emission intensity through fertilisers, machinery input, and planting structure adjustment (Ju et al. 2016; Tang and Chen 2022), because of the small land transfer areas, irregular land transfers, and unstable land property rights in the land transfer areas. Other scholars holding the opposite view focus on scale economies and scale returns after land transfer, and believe land transfer will increase the degree of agricultural intensification and improve the efficiency of agricultural production factors such as fertilisers and pesticides, thereby reducing agricultural carbon emission intensity (Ju et al. 2016; Lu et al. 2019; Cao et al. 2020). Therefore, the study of the impact of land transfer on agricultural carbon emissions is inseparable from the discussion of land management scale. The relationship between land

transfer and agricultural carbon emissions may change with changes in land management scale.

Land transfer and the area of transferred land are closely related to farmers' capabilities, and there are significant differences between large-scale and small-scale farmers in land transfer. Small-scale farmers often acquire land through unpaid transfers among relatives and friends, which are usually small in area and consist of disconnected inferior plots (Lyu et al. 2019). Although this can expand the farmers' land management scale, it may not necessarily increase the size per plot, which is still not conducive to fertiliser reduction and long-term land input. Small farmers have different expectations for the stability of the management rights of their own land and the land they transfer, which leads to differences in fertilisers application and long-term investment behaviour in agricultural production. They tend to increase short-term investment in fertilisers, pesticides etc. in the transferred land to obtain higher short-term yields without having to bear production externalities such as long-term land fertility decline (Ju et al. 2016; Tang and Chen 2022). Carbon emissions during the production and input of agricultural materials such as fertilisers and pesticides are an important source of carbon emissions from crop cultivation. At the same time, unstable land management rights are equivalent to random taxation on farmers. The increased possibility of land being taken away in the future will reduce farmers' enthusiasm for long-term investment (Mugizi 2022). In order to avoid the risk of not being able to recover long-term investment, farmers lack the motivation to invest in the long term and adopt water-saving technologies (Séogo and Zahonogo 2023). As a result, they are unable to reduce the energy consumption during the irrigation process, which is not conducive to carbon emission reduction in crop cultivation (Cillis et al. 2018).

Large-scale farmers have stronger management capabilities and higher production efficiency. They often transfer large plots of land for a fee, thereby improving the fragmentation of land and bringing about plots integration effect and scale operation benefits. Most studies have shown that agricultural production has significant scale economies at the plot level in terms of land investment, mechanical operation and irrigation facility investment (Yan et al. 2019; Yu et al. 2022). Therefore, the integration effect of plots brought by land transfer is conducive to reducing the input cost of technology adoption (Wu et al. 2018). The scale economy effect of land

operation brought by land transfer is also conducive to reducing the intensity of fertilisers use, thereby reducing agricultural carbon emissions. In addition, the adoption of new tools, the update and dissemination of knowledge regarding water and fertiliser utilisation, as well as pest and disease control, are all related to the scale of rural households. The scale effect of land transfer is conducive to sharing the fixed cost of learning new knowledge. Large households are more willing to adopt green production and management methods, change production and management methods, thereby reducing fertiliser and pesticide inputs and reducing agricultural carbon emissions.

In summary, based on the analysis of land management scale heterogeneity, it can be seen that there are obvious differences between farmers in land transfer, which in turn leads to differences in investment in fertilisers, pesticides and water-saving irrigation technologies. The relationship between land transfer and agricultural carbon emissions may be nonlinear.

MATERIAL AND METHODS

Agricultural carbon emissions. Generally agricultural carbon emissions come from six aspects: fertilisers, pesticides, agricultural films, machinery use, tillage, and irrigation. First, direct or indirect carbon emissions from agriculture caused by the production and use of fertilisers; second, carbon emissions caused by the production and use of pesticides; third, carbon emissions caused by the production and use of agricultural films; fourth, carbon emissions generated by the direct or indirect consumption of fossil fuels (mainly agricultural diesel) through the use of agricultural machinery; fifth, agricultural tillage destroys the soil organic carbon pool, and a large amount of organic carbon is lost to the air, resulting in carbon emissions; and sixth, the use of electricity during irrigation indirectly releases carbon from fossil fuels.

Agricultural films are rarely used in the surveyed area, and land circulation does not affect farmers' tillage behaviour, so there is no need to consider this part of carbon sources. Carbon emissions caused by the use of agricultural machinery are mainly in the sowing and harvesting stages. Farmers mostly purchase social services rather than purchasing machinery themselves, so land transfer does not affect carbon emissions from machinery use. Therefore, this paper mainly considers three types of carbon sources: fertilisers, pesticides and irrigation, when studying the impact path of farmland transfer on agricultural carbon emissions.

This article calculates agricultural carbon emissions based on the IPCC carbon emission coefficient method, and the formula is as follows:

$$TC = E_f + E_p + E_w \quad (1)$$

where: TC – agricultural carbon emissions per ha; E_f – fertiliser carbon emissions per ha; E_p – pesticide carbon emissions per ha; E_w – irrigation electricity carbon emissions per ha, kg CO₂.

The calculation formula for agricultural carbon emissions from fertilisers and pesticides is as follows:

$$Q_i = \sum_{i=1}^n q_i \times \rho_i \quad (2)$$

where: Q_i – carbon emission intensity of fertilisers and pesticides per ha, kg CO₂; q_i – number of fertilisers and pesticides used (kg), data obtained through questionnaires; ρ_i – carbon source emission coefficient of fertilisers and pesticides. According to existing literature, the carbon emission coefficients of fertilisers and pesticides are 0.895 6 kg/kg and 4.934 kg/kg, respectively (West and Marland 2002).

When calculating agricultural irrigation carbon emissions, carbon emissions are often estimated by multiplying the irrigation area by the emission coefficient, but the results based on the irrigation area estimate cannot accurately reflect irrigation carbon emissions. And because there are differences in energy utilisation efficiency in different regions, the selection of electricity and diesel carbon emission coefficients should be as consistent as possible with the actual situation in the region. The survey area of this article is a groundwater well irrigation area, which mainly uses electric pumps for irrigation. The carbon emissions from irrigation electricity account for a large proportion of local agricultural carbon emissions. Therefore, this article draws on existing literature (Zhang et al. 2021) and uses data such as irrigation times and irrigation electricity to more accurately calculate the agricultural irrigation carbon emission intensity. The calculation method of electricity carbon emissions is shown in Equation (3):

$$E_w = n * e * w \quad (3)$$

where: E_w – the average carbon emission per ha generated during agricultural irrigation (kg); n – the number of irrigation times; e – the carbon emission coefficient of electricity for irrigation (kg/kWh); w – the electricity consumption for irrigation (kWh).

The carbon emission coefficient of electricity is mainly taken from the coefficient of the North China region in the 'Guidelines for the Preparation of Provincial Greenhouse Gas Inventories', which is 1.246 kg/kWh. The number of irrigations and the amount of electricity consumed for irrigation were obtained through questionnaires.

Threshold regression model. Drawing on the threshold regression model proposed by Béland and Hansen (2000), this paper empirically analyses whether farmland transfer has a threshold effect on agricultural carbon emissions. The advantage of the threshold regression model method is that the judgment of the threshold value is based on the analysis of objective statistical indicators, rather than artificially selecting the sample mean or median of the variable as the grouping basis. The econometric model is constructed as follows:

$$Y_i = \alpha_{0i} + \beta_1 X_i \times IScale_i \leq \gamma + \beta_2 X_i \times I(Scale_i \geq \gamma) + \sum \gamma_i Z_{ki} + f_t + \xi_r + \varepsilon_i \quad (4)$$

where: Y_i – agricultural carbon emissions, measured by per ha agricultural carbon emission intensity; X_i – the area of agricultural land transfer; $Scale_i$ – farmers' actual cultivated land area, serving as a threshold variable; β_1 and β_2 – regression coefficients that capture the differential impacts of agricultural land transfer area on carbon emissions before and after the threshold is crossed; γ – the threshold value to be estimated; I – an indicator function that takes the value of 1 when the condition is satisfied, and 0 otherwise; Z_i – a control variable that will affect agricultural carbon emissions, and the variable selection is shown in Table 1; γ_i – a parameter to be estimated; f_t and ξ_r – regional fixed effects and time fixed effects, respectively; ε_i – a random disturbance term.

Analysis of the impact of farmland transfer on agricultural carbon emissions. The method of testing the mediation effect is to propose a mechanism variable that has a theoretically direct causal relationship with the explained variable, and regress the mechanism variable on the core explanatory variable to achieve the purpose of testing. To further reveal the mechanism of the impact of farmland transfer area on agricultural carbon emissions, the mediation model is constructed as follows:

$$M_i = \alpha_0 + \beta Scale_i + \sum \gamma_i Z_{ki} + f_t + \xi_r + \mu_i \quad (5)$$

$$Y_i = \alpha_0 + \beta M_i + \sum \gamma_i Z_{ki} + f_t + \xi_r + \mu_i \quad (6)$$

where: M_i – the mediating variable, pesticide and fertiliser input is represented by the per ha fertiliser and

Table 1. Variables and variables descriptive statistics

	Variable	Definition	Mean	Min.	Max.
Dependent variable	agricultural carbon emission intensity (Y)	agricultural carbon emissions per ha (kg)	3 765.872	200.166	16 707.620
Independent variable	agricultural land transfer area (X)	transferred land area (ha)	0.594	0	46.667
Mediating variables	water-saving technology adoption intensity ($M1$)	area adopting water-saving technologies / total cultivated land area	0.865	0	1
	fertiliser and pesticide input ($M2$)	actual fertiliser and pesticide input per ha (kg)	877.924	141	2877
Threshold variable	land management scale (T)	actual total cultivated land area (ha)	1.226	0.067	46.667
Control variables	gender ($Z1$)	0 = female; 1 = male	0.830	0	1
	age ($Z2$)	unit: year	58.757	24	82
	years of agricultural production ($Z3$)	unit: year	36.144	1	65
	number of plots ($Z4$)	actual number of cultivated land plots (plots)	3.382	1	26
	labour force ($Z5$)	unit: person	1.864	1	7
	non-agricultural income ratio ($Z6$)	household non-agricultural income / total income	0.586	0	1
	family income level ($Z7$)	1 = better; 2 = upper-middle level; 3 = average level; 4 = lower-middle level; 5 = poor	3.144	1	5
	soil fertility ($Z8$)	1 = poor; 2 = moderate; 3 = fertile	2.346	1	3

Source: Author's own elaboration

pesticide input, and irrigation technology input is represented by the intensity of water-saving technology adoption, that is, the proportion of water-saving technology adoption area to the total area (%); Z_{ki} – a series of control variables; α_0 , β , γ_i – parameters to be estimated; f_i and ξ_r – regional fixed effects and time fixed effects, respectively; μ_i – a random disturbance term; Variables are listed in Table 1.

Data sources. The research area of this paper, the Hebei Province, is a major grain-producing region in China. It mainly grows wheat, maize, and cotton, and is highly dependent on groundwater irrigation. Groundwater accounts for more than 57.9% of the irrigation water. Irrigation requires pumping water from

wells, and the competition between water and grain is prominent. The survey areas in this paper include the Yuanshi County, Shijiazhuang City, Hebei Province, Cheng'an County, Handan City, and Nanpi County, Xian County, and Haixing County in Cangzhou City, which are located in areas with severe groundwater overexploitation. The data in this paper come from the field surveys conducted by the research team in July 2019 and November to December 2020. The farmer questionnaire adopts a combination of stratified sampling and random sampling. In each county, 6–10 townships (towns) were selected; in each township (town), 2–6 villages were selected; and in each village, 10–20 farmers were selected after eliminating

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invalid questionnaires and farmers using surface water irrigation, 767 valid questionnaires were obtained as the basis for the analysis of this paper. Table 1 shows that among the 767 valid questionnaires, 129 farmers were transferred households, accounting for 16.86% of the total number of farmers surveyed, mainly small-scale. The transfer area of farmers is less than 0.33 ha, accounting for 40.53%, and that of farmers is less than 1 ha, accounting for 65.26%. The land transfer period of less than 3 years accounts for 52.12%, indicating that the land transfer between farmers in the survey area is mainly short-term.

RESULTS AND DISCUSSION

Carbon emission

Figures 1 to 3 show the distribution of carbon emissions from fertilisers, pesticides and irrigation electricity used by farmers in the survey area, expressed in terms of carbon emission intensity (kg). Figure 1 shows the distribution of direct or indirect carbon emissions from agriculture caused by the use of fertilisers for different crops, which are ranked in order of carbon emission intensity: wheat, cotton and maize.

Figure 2 shows the direct or indirect carbon emissions from agriculture caused by the use of pesticides for different crops. The order of carbon emission intensity is cotton, wheat, and maize. Because cotton is an economic crop, the number of pesticides used is much greater than that of food crops such as wheat and cotton.

Figure 3 shows the distribution of carbon emissions generated by the indirect consumption of fossil fuels during the irrigation of different crops using electricity. The order of carbon emission intensity is wheat, cotton and maize. This is related to the amount of irrigation water required for the growth of different crops. The irrigation water consumption of maize is greater than that of cotton.

Figure 4 shows the carbon emission intensity of three carbon sources: fertilisers, pesticides, and irrigation electricity. The order of carbon emission intensity is that irrigation electricity has the largest carbon emission, followed by fertiliser use, and the smallest is pesticide use. The average carbon emission of fertilisers is 823.40 kg, the average carbon emission of pesticides is 47.51 kg, and the average carbon emission of irrigation electricity is 2918.61 kg. The main source of carbon emissions in the planting industry in the surveyed area is irrigation electricity, and fertilisers are the second largest carbon source.

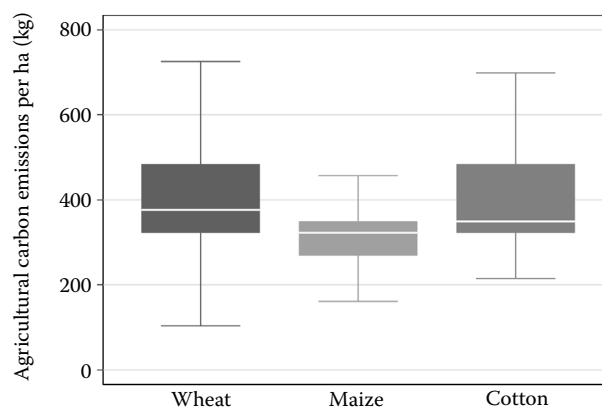


Figure 1. Carbon emission intensity of fertiliser use

Source: Author's own elaboration

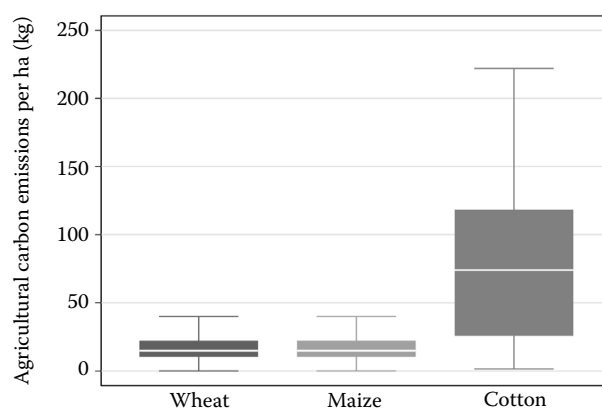


Figure 2. Carbon emission intensity of pesticide use

Source: Author's own elaboration

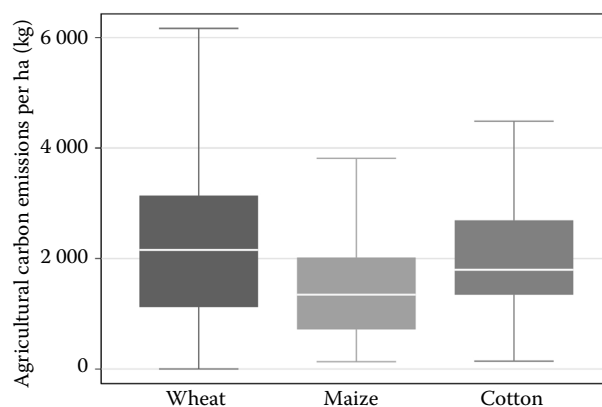


Figure 3. Carbon emission intensity of irrigation electricity consumption

Source: Author's own elaboration

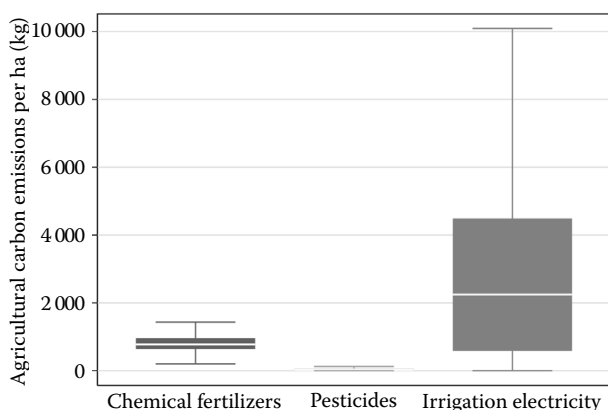


Figure 4. Comprehensive carbon emission intensity of different carbon sources

Source: Author's own elaboration

Impact of farmland transfer on agricultural carbon emissions

From the above analysis, we can see that if the transfer area is used as the core explanatory variable, only the linear impact on carbon emission intensity is considered, which may ignore the marginal impact of different farmland scale operators on carbon emissions. Therefore, this paper draws on the threshold regression model proposed by Hansen to test whether land transfer at different scales has a threshold effect on carbon emission intensity. The steps of the threshold model include threshold effect significance test, threshold effect authenticity test and threshold regression results.

Test of significance of threshold effect. Before threshold regression, it is necessary to test the existence of threshold effect and determine the number of threshold values. The Bootstrap method proposed by Hansen is used to test the existence of single threshold, double threshold and triple threshold effects in turn. The F -statistic and the P -value obtained by 'self-sampling method' (Bootstrap) are shown in Table 2. The results show that only the single threshold effect is significant, and the corresponding self-sampling P -value is 0.000, while the double threshold and

triple threshold self-sampling P -values are 0.191 and 0.506 respectively, which are not significant, indicating that there is no double threshold and triple threshold. Therefore, the following analysis will be based on the single threshold model.

Test of the authenticity of threshold effect. After confirming the existence of threshold effects and the number of threshold values, it is necessary to further estimate the specific threshold value. Table 3 shows the threshold estimates of the impact of land transfer on agricultural carbon emissions and their corresponding 95% confidence intervals. The estimated value of the threshold parameter refers to the value of γ when the likelihood ratio test statistic LR is zero. In the single threshold model, it corresponds to 15, that is, the threshold value of land management scale is 15, 'which corresponds to an area of 1 ha.'

Table 3. Threshold estimates and confidence interval tests

Single threshold model	Threshold estimates	95% confidence interval
	15	[11.000, 16.000]

Source: Author's own elaboration

Threshold effect results. The regression results obtained using the threshold model (Table 4) show that the impact of land transfer area on carbon emission intensity has a threshold effect. When the land operation scale is lower than the threshold value of 1 ha, the impact coefficient of land transfer area on carbon emission intensity is 13.50, which is significant at the 1% statistical level, that is, agricultural carbon emission intensity increases with the expansion of land transfer area; when the land operation scale is higher than the threshold value of 1 ha, the impact coefficient of land transfer area on carbon emission intensity is -0.232 , which is significant at the 1% statistical level, indicating that when the land operation scale exceeds the threshold value, the impact of land transfer on carbon emission intensity turns from positive to negative, and agricultural carbon emission intensity decreases with

Table 2. Threshold effect test

Model	F -value	P -value	Bootstrap times	Critical value		
				1%	5%	10%
Single threshold	11.862***	0.000	800	7.430	4.323	2.967
Double threshold	0.578	0.234	800	11.131	5.824	3.062
Triple threshold	1.088	0.325	800	6.727	3.999	2.832

Source: Author's own elaboration

Table 4. Regression results of the influence of farmland transfer on agricultural carbon emissions in different scales

Variables	(1) Agricultural carbon emission intensity (Y)
X (land management areas < threshold value)	13.50*** (3.35)
X (land management areas > threshold value)	–0.232** (–2.21)
Gender ($Z1$)	–20.55 (–1.32)
Age ($Z2$)	–2.329 *** (–2.92)
Years of agricultural production ($Z3$)	0.992 (1.50)
Number of plots ($Z4$)	1.814 (0.72)
Labour force ($Z5$)	–2.025 (–0.28)
Non-agricultural income ratio ($Z6$)	–24.90 (–1.62)
Family income level ($Z7$)	–0.620 (–0.08)
Soil fertility ($Z8$)	–13.57 (–1.34)
Constant	–472.5*** (7.87)
Time fixation effect	yes
Regional fixed effects	yes
Observations	767
R^2	0.411

*, ** and ***significance at 0.1, 0.05 and 0.01 levels, respectively; t -statistics in parentheses

Source: Author's own elaboration

the expansion of land transfer area. The average land operation scale of farmers who have not carried out land transfer in the survey area is about 0.355 ha, which is 0.645 ha different from the threshold value, indicating that the land transfer area in the region must be at least 0.645 ha to reduce carbon emissions in agricultural production.

Mechanism test of farmland transfer on farmland input behaviours

Adoption of water-saving technologies. Table 5 verifies the mediating effect of water-saving technology adoption in samples before and after the threshold value. The impact of land transfer on agricultural carbon emission intensity has been verified in the baseline regression results, so the following article focuses on reporting the estimated results of the mediating variables. According to the previous analysis, small-scale farmers lack the motivation to invest in water-saving technologies in order to avoid the risk of not being able to recover long-term investment; the scale management benefits and land integration effects of large-scale

farmers after transferring land are conducive to reducing the unit cost of technology adoption, thereby promoting the adoption of water-saving technologies. This paper divides the sample into two sub-samples based on the threshold value obtained in Table 3 to explore the impact of land transfer of farmers at different scales on the adoption of water-saving technologies.

Columns (1 and 2) of Table 5 show the impact on water-saving technologies adoption intensity in samples below the threshold. Column (2) adds time and region fixed effects on the basis of column (1). From the coefficients, it can be seen that the land transfer of sample farmers below the threshold has a negative impact on the adoption of water-saving technologies, with coefficients of –6.906 and –6.878, and is significant at the 1% statistical level, indicating that there is a short-term phenomenon in the agricultural production behaviour of farmers who transfer land, and land transfer has an inhibitory effect on the adoption of water-saving technologies; the regression results of column (3) show that the intensity of water-saving technology adoption has a significant negative impact on the intensity of agricultural carbon emissions.

Columns (4 and 5) show the impact of land transfer on the adoption intensity of water-saving technologies for samples above the threshold. Column (5) adds time and region fixed effects on the basis of column (4). From the coefficients, we can see that the coefficients of the impact of land transfer on the adoption intensity of water-saving technologies for sample households above the threshold have changed from negative to positive, which are 0.080 and 0.082 respectively, and are significant at the 5% statistical level, that is, the negative effect of land transfer on the adoption of water-saving technologies has disappeared and has produced a positive impact. The reason is that for farmers with a large area of transferred farmland, as the scale of operation expands, on the one hand, the scale effect gradually emerges, reducing the cost of water-saving technology sharing, that is, the scale operation benefit; on the other hand, the large-scale farmland after land transfer provides good objective conditions for the adoption of water-saving irrigation technology, that is, the land integration effect. The regression results in column (6) show that the adoption intensity of water-saving technologies has a significant negative impact on the intensity of agricultural carbon emissions. So far, the mediation effect test has been completed, indicating that the scale of land transfer can affect the intensity of agricultural carbon emissions through the intensity of water-saving technology adoption.

Table 5. Influence of farmland transfer on the adoption intensity of water-saving technologies

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Samples below the threshold			Samples above the threshold		
	<i>MI</i>	<i>MI</i>	<i>Y</i>	<i>MI</i>	<i>MI</i>	<i>Y</i>
<i>X</i>	–6.906*** (0.281)	–6.878*** (0.283)	5.657 (5.766)	0.080** (0.031)	0.082** (0.032)	–0.236* (0.126)
<i>MI</i>			–1.310** (0.583)			–0.634* (0.373)
<i>Z1</i>	–0.149 (1.153)	–0.174 (1.170)	–29.901* (17.134)	15.084 (10.006)	7.036 (9.996)	–8.234 (38.832)
<i>Z2</i>	0.130** (0.058)	0.150** (0.059)	–2.341*** (0.862)	0.051 (0.576)	0.438 (0.570)	–0.628 (2.217)
<i>Z3</i>	–0.077 (0.049)	–0.093* (0.049)	1.284* (0.726)	–0.246 (0.439)	–0.323 (0.427)	–1.159 (1.658)
<i>Z4</i>	–0.416* (0.251)	–0.515* (0.277)	–1.314 (4.068)	–2.227** (0.910)	–2.369*** (0.902)	–2.192 (3.607)
<i>Z5</i>	0.354 (0.555)	0.351 (0.559)	–7.567 (8.184)	1.851 (3.973)	2.368 (3.846)	12.484 (14.933)
<i>Z6</i>	–1.517 (1.143)	–1.606 (1.154)	–35.800** (16.913)	0.062 (10.100)	0.570 (9.942)	19.583 (38.535)
<i>Z7</i>	–0.635 (0.597)	–0.666 (0.598)	–8.414 (8.764)	–3.224 (4.718)	–4.479 (4.593)	29.634 (17.880)
<i>Z8</i>	0.490 (0.741)	0.558 (0.771)	–12.203 (11.288)	10.740* (5.934)	11.651** (5.857)	–1.068 (23.116)
Constant	88.816*** (4.164)	89.970*** (4.256)	448.735*** (81.436)	43.477 (32.890)	20.862 (32.416)	140.717 (125.886)
Time fixation effect	no	yes	yes	no	yes	yes
Regional fixed effects	no	yes	yes	no	yes	yes
Observations	645	645	645	122	122	122
<i>R</i> ²	0.510	0.514	0.405	0.173	0.258	0.539

*, ** and ***significance at 0.1, 0.05 and 0.01 levels, respectively; standard errors in parentheses

Source: Author's own elaboration

Input of fertilisers and pesticides. Table 6 verifies the mediating effect of fertiliser and pesticide input in samples before and after the threshold value. Based on the analysis of relevant literature (Ju et al. 2016; Tang and Chen 2022), the transfer of farmland by small-scale farmers has failed to change the situation of small-scale agricultural operations, which is not conducive to the reduction of pesticides and fertilisers. However, the situation is different for large-scale farmers. Columns (1 and 2) in Table 6 show the impact of land transfer on fertiliser and pesticide inputs in samples below the threshold. Column (2) adds time and region fixed effects on the basis of column (1). The land trans-

fer of sample farmers below the threshold value has a positive and significant impact on fertiliser and pesticide input, with coefficients of 1.123 and 1.396, respectively, that is, farmers are more inclined to increase fertiliser and pesticide input after land transfer; the regression results in column (3) show that agricultural carbon emission intensity increases with the increase of fertiliser and pesticide input.

Columns (4 and 5) show the impact of land transfer on pesticide and fertiliser input for samples above the threshold. Column (5) adds time and region fixed effects on column (4). The coefficients show that land transfer for sample farmers above the threshold has

Table 6. The influence of land transfer on the input of fertilisers and pesticides

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Samples below the threshold			Samples above the threshold		
	<i>M2</i>	<i>M2</i>	<i>Y</i>	<i>M2</i>	<i>M2</i>	<i>Y</i>
<i>X</i>	1.123** (0.559)	1.396*** (0.504)	9.806** (3.797)	–0.032** (0.015)	–0.026* (0.015)	–0.205* (0.116)
<i>M2</i>			3.480*** (0.298)			3.225*** (0.754)
<i>Z1</i>	–9.676*** (2.291)	–5.183** (2.081)	–11.635 (15.676)	–2.562 (4.872)	–0.567 (4.632)	–10.866 (36.283)
<i>Z2</i>	–0.178 (0.115)	–0.213** (0.104)	–1.798** (0.784)	–0.358 (0.281)	–0.436 (0.264)	0.501 (2.097)
<i>Z3</i>	0.206** (0.097)	0.172* (0.088)	0.806 (0.661)	0.220 (0.214)	0.270 (0.198)	–1.823 (1.561)
<i>Z4</i>	0.529 (0.498)	0.355 (0.493)	–1.873 (3.696)	–0.219 (0.443)	–0.516 (0.418)	0.973 (3.298)
<i>Z5</i>	0.244 (1.103)	–0.918 (0.994)	–4.831 (7.455)	–0.016 (1.935)	0.679 (1.782)	8.792 (13.969)
<i>Z6</i>	2.311 (2.271)	0.686 (2.052)	–36.085** (15.377)	1.434 (4.918)	–0.407 (4.607)	20.535 (36.086)
<i>Z7</i>	–1.639 (1.187)	–1.092 (1.064)	–3.740 (7.978)	0.417 (2.297)	1.410 (2.128)	27.928* (16.704)
<i>Z8</i>	–1.800 (1.473)	–2.784** (1.371)	–3.246 (10.307)	–0.906 (2.889)	0.382 (2.714)	–9.691 (21.263)
Constant	74.577*** (8.272)	72.954*** (7.569)	77.031 (60.766)	79.919*** (16.014)	74.081*** (15.022)	–111.464 (130.234)
Time fixation effect	no	yes	yes	no	yes	yes
Regional fixed effects	no	yes	yes	no	yes	yes
Observations	645	645	645	122	122	122
<i>R</i> ²	0.055	0.249	0.507	0.076	0.249	0.595

*, ** and ***significance at 0.1, 0.05 and 0.01 levels, respectively; standard errors in parentheses

Source: Author's own elaboration

a negative and significant impact on fertiliser and pesticide input, which are –0.032 and –0.026 respectively. That is, land transfer by large-scale farmers has a negative effect on fertiliser and pesticide input. Farmers face different production constraints and planting behaviours due to different land management scales. Comparing the coefficients of columns (1–2 and 4–5), it can be seen that the scale economy effect of land management brought about by land transfer by large-scale farmers is conducive to improving fertiliser application efficiency, reducing fertiliser use intensity, and thus reducing agricultural carbon emissions; while

small-scale farmers tend to increase fertiliser and pesticide input in order to obtain higher yields in the short term, thereby increasing agricultural carbon emissions. The regression results of column (6) show that fertiliser and pesticide input have a significant positive impact on agricultural carbon emission intensity. This completes the test of the mediating effect, indicating that the scale of land transfer can affect agricultural carbon emission intensity through the input of fertilisers and pesticides.

The above results show that farmland transfer can change the way farmers input agricultural factors in the

production process, thereby affecting agricultural carbon emissions. If the scale of farmers' land management is lower than the threshold value, then farmers' land transfer will reduce the adoption of water-saving technologies and increase the use of pesticides and fertilisers, which is manifested as short-term agricultural production behaviour, thereby increasing agricultural carbon emissions; if it is higher than the threshold value, then farmers' land transfer will increase the intensity of water-saving technology adoption and reduce the use of pesticides and fertilisers, thereby reducing agricultural carbon emissions.

DISCUSSION

Impact of farmland transfer on carbon emissions.

This paper concludes that there is a threshold effect in the impact of farmland transfer on agricultural carbon emissions. When the farmland scale is below the threshold value, farmland transfer promotes carbon emissions, while when it is above the threshold value, it suppresses carbon emissions. The threshold value is 1 ha. This reveals that only when a farmer's land scale reaches at least 1 ha can land transfer contribute to carbon emission reduction, thereby providing a policy-relevant reference for promoting land consolidation in support of low-carbon agriculture. This paper concludes that the impact of farmland transfer on agricultural carbon emissions is not a simple linear relationship. Other scholars, based on macro-level analyses, have suggested that the impact of land transfer on agricultural carbon emissions is also influenced by factors such as the level of urbanisation (Tang and Chen 2022), the development of agricultural socialised services (Li et al. 2024), and regional disparities (Quan et al. 2024). Therefore, the findings of this study are consistent with those of previous research.

Impact of farmland transfer on agricultural inputs. This paper further explores the mediating mechanism of the impact of farmland transfer on agricultural carbon emissions. The conclusion is that small-scale farmers increase the input of chemical fertilisers and pesticides after transferring in land, while large-scale operation is conducive to reducing the use of chemical fertilisers and pesticides and increasing the investment in water-saving irrigation technologies. This means that the effect of farmland transfer on carbon emission reduction is mainly achieved by reducing the input of chemical fertilisers and pesticides and increasing the investment in water-saving technologies. This conclusion is consistent with findings from existing literature, which indicates that promoting land transfer to expand

farm operational scale can encourage farmers to reduce their use of chemical inputs (Ju et al. 2016), adopt green organic fertilisers (Lu et al. 2019), and increase long-term agricultural investments (Cao et al. 2020). Scholars' studies on African countries have also reached similar conclusions. Mugizi (2022) pointed out that farmland transfer in Uganda affects farmers' behaviour of using chemical fertilisers. Séogo and Zohonogo (2023) pointed out that farmland transfer can promote large-scale farmers' investment in water conservancy facilities.

CONCLUSION

Based on the questionnaire data of farmers in the groundwater irrigation area of Hebei Province, this paper studies the impact of farmland transfer on carbon emissions from agricultural planting and obtains the following conclusions:

i) The impact of agricultural land transfer on agricultural carbon emissions is scale heterogeneous. The land transfer of small-scale farmers increased carbon emissions, while the land transfer of large-scale farmers reduced carbon emissions. The threshold value of land operation scale is 1 ha in case study region. To reduce carbon emissions in agricultural production, the land transfer area in the survey area must reach at least 0.645 ha.

ii) The main factors affecting agricultural carbon emissions of land transfer are the adoption of water-saving technologies and the use of fertilisers and pesticides. Small-scale land transfer tends to increase the input of fertilisers and pesticides, which inhibits the adoption of water-saving technologies, and then leads to an increase in agricultural carbon emission intensity. Large-scale land transfer leads to significant reductions in pesticides and fertilisers, and the adoption of water-saving technologies in the irrigation process reduces irrigation electricity consumption, which is conducive to reducing agricultural carbon emissions.

Based on the conclusions of this study, the suggestions are proposed:

i) Accelerate the transfer of agricultural land, reasonably guide farmers to moderately expand their farm land scale, and give full play to the reduction effect of agricultural land transfer on agricultural carbon emission intensity. (i) Strengthen the construction of the farmland transfer trading platform, improve the land dispute and conflict resolution mechanism, safeguard the interests of all parties involved in the transfer, and protect the rights and interests of the transferee farmers over the transferred land. (ii) Introduce incentive policies to encourage farmers to transfer land for

a long term. This would help stabilise land management expectations, promote large-scale management, reduce chemical input use, and encourage investment in water-saving technologies.

ii) Land transfer should be integrated with incentive policies for water-saving subsidies to enhance the adoption of water-saving technologies and maximise their role in promoting agricultural carbon emission reduction. *(i)* It is recommended to adopt an integrated approach to the management of water and soil resources, draw upon and disseminate the successful practices of modern irrigation districts. *(ii)* Develop water-saving technical equipment suitable for different land scales, establish a sound supervision and evaluation mechanism, truly achieve the goal of water-saving technologies promoting agricultural carbon emission reduction, and promote the green development of agriculture.

iii) For small-scale farmers, agricultural carbon emissions can be reduced by reducing the input of chemical fertilisers and pesticides and irrigation water use. *(i)* Improve the agricultural green production policies to guide farmers to adopt efficient fertilisation models. Promote cost-effective, simple, effective, and farmer-friendly technical models for reducing pesticide use. Guide farmers to apply fertilisers scientifically, promote the use of organic fertilisers and new high-efficiency fertilisers, and improve agricultural fertilisers use efficiency. *(ii)* The government should strengthen the construction of the agricultural social service system, guide social service providers to carry out water-saving irrigation services, and encourage small-scale farmers to save irrigation water.

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