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EDITED BY
Tibebu Kassawmar,
Addis Ababa University, Ethiopia

REVIEWED BY
Tariku Dejene,
Addis Ababa University, Ethiopia
Thanh Thi Nguyen,
University of Kassel, Germany

*CORRESPONDENCE
Guoming Du
✉ nmgdgm@126.com

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The influence of cultivated land transfer and Internet use on crop rotation

Chang'an Liang[1], Guoming Du[1,2]* and Bonoua Faye[1]

[1]School of Economics and Management, Northeast Agricultural University, Harbin, China, [2]School of Public Administration and Law, Northeast Agricultural University, Harbin, China

In the context of China's digital transformation and agricultural modernization, exploring the impact of cultivated land transfer and Internet use on crop rotation holds significant importance for promoting sustainable use of cultivated land and ensuring the supply of agricultural products. This study utilizes an ordered logistic regression model to investigate this issue, based on a social survey of 489 households in Heilongjiang Province. Our findings reveal that (1) cultivated land transfer and Internet use both promote crop rotation, but cultivated land transfer is more efficient than Internet use. In addition, two-years cultivated land transfer are more effective than one-year, (2) The analysis of the mechanism indicates that both have the most significant promotion effect in the maize-soybean transition zone, and the promotion effect of cultivated land transfer is mainly observed in the older age group, while Internet use is mainly observed in the younger age group. As aging farmers become more critical, the role of cultivated land transfer does not change significantly, while the role of Internet use decreases. Furthermore, the interaction effect of cultivated land transfer and Internet use is not conducive to crop rotation in the maize-soybean transition zone, but it can facilitate crop rotation in older age groups.

KEYWORDS

Internet use, digital divide, cultivated land transfer, crop rotation, conservation tillage

1. Introduction

Crop rotation is an inevitable step to implementing ecological civilization policies and protecting cultivated land. Currently, China is facing a serious challenge with food security and a structural problem with agricultural supply (Zhan et al., 2018; Baylis et al., 2019). The issue of food security is mainly reflected in the protection of cultivated land. China's cultivated land area is decreasing year over year, but grain production is increasing. This phenomenon reflects the growth of China's agricultural production technology but also implies that China's cultivated land is being used intensively. This phenomenon is particularly prominent in the black soil region of Northeast China, manifested by the black soil's thinning and hardening (Xingwu et al., 2012; Wang et al., 2022). This situation not only means that the potential for sustainable use of cultivated land in the black soil region has declined, but it has also caused more serious soil erosion problems (Maojuan et al., 2019).

China has recognized this problem and proposed protecting the black soil as protecting a "panda"(http://www.news.cn/politics/2021-10/17/c_1127966614.htm [2022-12-19]), which indicates that the black soil in Northeast China is crucial for crop production and national food security. Then, China's government has focused on supply-side reform in its economic development of the agricultural system, particularly since 2015. The problem on the supply side of China's agricultural products is mainly the high import of soybeans (Wei and Junfeng, 2019).

Combining these two challenges, the Chinese government aimed to protect cultivated land and restructure the supply of agricultural products by strengthening the crop rotation in the black soil region. So, the challenge is how to effectively encourage farmers in Northeast China to carry out crop rotation which is of great significance to the locally cultivated land ecosystem health and the agricultural product supply in the country. In response to this issue, in August 2022, a social survey was conducted by the "Sustainable Utilization of Black Land" team in typical black soil regions, namely Baiquan, Wangkui, and Jixian counties.

Crop rotation emphasizes the cultivation of different crops in different years, which achieves the conservation of land strength and the reduction of production inputs and improves the overall profitability of agricultural production (Munkholm et al., 2013; Bowles et al., 2020; Yu et al., 2022), which is one kind of conservation tillage technique. Whether farmers adopt conservation tillage techniques is affected by many factors. For instance, age, labor force, cognition level, cultivated land area, agricultural machinery supply, and government subsidies (Teklewold et al., 2013; Grabowski and Kerr, 2014; Chalak et al., 2017; Khataza et al., 2018; Yang and Sang, 2020; Guo et al., 2022). Among them, the cognition level represents farmers' willingness, while the cultivated land area is related to the scale economy of agricultural production. In the process of agricultural production patterns, the consolidation of contiguous arable land serves as a crucial prerequisite. Due to the household contract responsibility system, Chinese rural families own almost equal areas of cultivated land (depending on local conditions) and are scattered (Xie and Jiang, 2016). So, the fulfillment of this condition primarily relies on the transfer of cultivated land, referring to the transfer of land use rights for cultivated land. In addition, the farmer's age and low education level in our study area are critical challenges. Most of the respondents' education levels do not exceed the primary school level. In the context of China's digital transformation, previously published papers have focused on the impact of internet use on the cognitive limitations of farmers and have identified the positive effects of internet usage in this regard (Kan, 2020; Zhang et al., 2022; Zhou et al., 2023). However, this situation presents several shortcomings. First, the current studies regard crop rotation as a form of conservation farming and do not fully consider the high stability requirement of crop management rights for crop rotation. This characteristic may determine that short-term crop management rights cannot promote crop rotation (Zhao et al., 2020; Yu et al., 2022). Then, crop rotation requires consideration of the combined benefits of growing different crops. This context involves climatic suitability under different accumulation conditions (Xiaozhong et al., 2017; Haijiang et al., 2019). Accordingly, it's worth noting that the spatial perspective has not been deeply analyzed in previous studies. Second, crop rotation is currently being piloted in the black soil region of Northeast China, and the policy content changes yearly (http://hlj.people.com.cn/n2/2022/0221/c220027-35143454.html [2022-12-18]). Additionally, because local farmers are getting older, accessing current and useful policy information has become problematic. The difference between this and technical awareness issues is that policy information requires accuracy and timeliness. Therefore, different groups of farmers may lead to different outcomes in Internet use (Twumasi et al., 2021; Khan et al., 2022). The effects of this issue are not clearly described in the previous studies; correspondingly, it is considered a shortcoming.

Therefore, based on social surveys and existing scientific research results, this research aims to investigate the effects and mechanisms of cultivated land transfer and Internet use behavior on crop rotation. Then, it discusses whether this effect has different manifestations in different accumulated temperature conditions and age groups. This paper is arranged as follows: part I presents the context, including a background introduction and literature review; part II analyzes the theoretical mechanisms of cultivated land transfer and Internet use affecting farming rotation and proposes research hypotheses; part III introduces the econometric model setting and data sources, and conducts a descriptive statistical analysis of the data; part IV reports and analyzes the estimation results; and part V focuses on the discussion and conclusions.

2. Theoretical analysis and hypothesis

Crop rotation is the practice of growing crops on the same land in a predictable sequence at various periods of the year, forming a rotation within a cycle. At the same time, crop rotation also has specific positive spatial externalities. The research in agronomy has shed light on the fact that maize-soybean intercropping effectively boosts maize yields due to the nitrogen fixation of legumes, the activation of soil phosphorus by root secretions, and the shading effect of maize on soybean yields (Yu et al., 2009; Yamei et al., 2020). This situation implies a "You cannot have your cake and eat it" situation between the finely fragmented plots for maize and soybean. Moreover, the benefits of conservation tillage for agricultural production also concern crop rotation. However, in contrast to straw mulch and deep tillage, which can be applied in the same year and obtain the effect, crop rotation needs to be implemented over several years to get higher returns over a longer period (Munkholm et al., 2013; Shuhao et al., 2014; Bowles et al., 2020). Compared to other conservation tillage techniques, it takes longer to complete a cropping pattern rotation. Therefore, it requires higher stability of farmland management rights and has the disadvantages of time and cost. The cultivated land transfer can mitigate the problem of cultivated land fragmentation (Xiao et al., 2011). Inevitably, short-term contracts for the transfer of cropland will result in a loss of externalities for farmers' crop rotation (Bo and Ruimei, 2021). Long-term, stable cultivated land transfer not only alleviates the problem of fragmentation but also addresses the 'positive time externality' of crop rotation. Therefore, stable cropland management rights are essential for implementing crop rotation, and the transfer of cultivated land for a long period should be an important step toward implementing crop rotation. As a result, a multi-year cultivated land transfer is more effective than a short-term one to carry out crop rotation. The time limit of the cultivated land transfer becomes an important factor for farmers to decide whether to practice crop rotation or not.

Also, crop rotation requires a high level of cognitive ability. Crop rotation is difficult to implement if farmers lack technical and policy knowledge and awareness of crop rotation. For this study, both technical and policy aspects are involved. Regarding technology, the land area under maize cultivation in the black soil region of Northeast China has been expanding due to the significant changes in temperature conditions under climate change (Ray et al., 2015). Due to the influence of international markets, the land area under soybean cultivation in the black soil region has decreased since China joined the World Trade Organization in 2001. Since 2000, under the combined influence of changing climatic conditions and international market shocks, the diversity of crops in the black soil region has significantly reduced, and the cropping pattern of mainly maize continuous crops has gradually structured (Han and He, 2012). Some of the younger groups of farmers have less experience in making practical decisions about cropping behavior and have not been able to appreciate the long-term effects of crop rotation practically. The lack of intuition and perceptual understanding of crop rotation has led to a lack of technical knowledge (Weizhen et al., 2017; Li and Liqi, 2020). This situation is not conducive to them carrying out crop rotation (Weizhen et al., 2017). Regarding policy, to enable operators of crop rotation to be duly compensated, China began exploring a trial crop rotation exercise in 2016, with a policy subsidy of RMB 150 per mu (a unit of area in China, about 666.7 square meters) for farmers who carry out crop rotation. Now there are still many details to be optimized in practice. Firstly, the annually updated pilot implementation program for crop rotation and fallowing has different target requirements for the area to be rotated in different areas. This information often needs to be passed down from the Ministry of Agriculture and Rural Development before it reaches the farmer. This issue runs the risk of delaying the farming process in practice. Secondly, the problem of population migration and farmer aging is critical in black soil regions (Zuopeng et al., 2021). Farmers are often typically a disadvantaged information group. Or, crop rotation truly has a high level of financial subsidies.[1] However, it is often difficult for specific information about the implementation program of the pilot crop rotation fallow to reach the increasingly aging group of farmers in the black soil region in a timely and effective manner (Yusheng et al., 2016; Zuopeng et al., 2021). Farmers' insufficient awareness of crop rotation systems and area standards makes it difficult to be effectively motivated by the policy, which greatly weakens their enthusiasm to carry out crop rotation. During the social survey, farmers affirmed that they could not obtain crop rotation subsidies and were generally unsatisfied with the crop rotation policy.

Both cognitive problems are expected to be alleviated through the Internet (Li and Liqi, 2020; Zheng et al., 2022). The Internet provides farmers with an effective channel to acquire new knowledge and information. Farmers' internet usage behavior implies that they are able to obtain more information about crop rotation technologies and policies. Especially in sparsely populated areas, digital technology can alleviate the characteristics of geographical constraints, allowing information to be communicated effectively and quickly between different groups (Zhuqing et al., 2013). Continuous innovation in communication technology has greatly reduced the cost of Internet communication, while the construction of digital villages has provided rural residents with good Internet infrastructure. The current level of digitization in Chinese society is increasing. Added to this background, the price of friendly mobile devices with adequate information facility coverage has effectively increased the informational level of rural residents. Thus the role of Internet use in various aspects of farmers' behavior is beginning to receive widespread attention (Michels et al., 2019; Liang et al., 2022). Internet use can effectively alleviate the information exclusion suffered by rural residents (Zhang et al., 2022), which is essential for farmers to have timely and accurate access to effective information about crop rotation. Relevant studies related to conservation farming have mainly concluded that Internet use can enhance farmers' cognition and thus promote adoption behavior (Wenhuan and Guixia, 2021; Zhang et al., 2022; Zhou et al., 2023). So, in the contribution of this research, this role may be reflected in the fact that farmers have more accurate and effective access to technical and policy information about crop rotation through Internet use, which helps them carry out crop rotation.

The conclusion that stability of land rights can improve conservation farming should, in our view, be accompanied by additional preconditions, such as consideration of regional heterogeneity or age heterogeneity (Xiaozhong et al., 2017; Haijiang et al., 2019; Chandio et al., 2022). In areas with high cumulative temperature levels, crop rotation subsidies can hardly bridge the yield gap between maize and soybeans and cannot effectively promote crop rotation. In areas with low cumulative temperature levels, the impact of other factors is limited because the yield gap between maize and soybeans is small, and the proportion of basic crop rotation is high. In areas with middle cumulative temperature levels, where suitable for both maize and soybeans, so it also forms a maize-soybean transition zone in the agricultural landscape. In this region, the yield gap between maize and soybean is at an intermediate level and more susceptible to fluctuations due to other factors. Therefore, more significantly affected by land rights stability and Internet use. In addition, rural areas are currently facing a severe aging problem, and Internet use may create an information divide between different groups of farmers, resulting in "elite capture." Younger farmers are more likely to benefit from access to accurate information through Internet use (Zhuqing et al., 2013).

To some extent, the transfer of cultivated land is the tool basis for farmers to carry out crop rotation, and Internet use improves the farmers' cognition level. The transfer of cultivated land is helpful to crop rotation by solving the externalities in space and time. The use of the Internet deepens farmers' cognition of the ecological and production benefits of crop rotation through the acquisition of technical and policy information. Increasing the material base motivates farmers to expand their skills and cognitive capabilities. The improvement in the cognition level encouraged the farmer to expand the production scale. These two factors should therefore be able to facilitate each other's effects. However, other studies have shown that Internet use can promote farmers' non-agricultural employment and expand income sources to some extent (Xiaona and Xuekai, 2020; Fang et al., 2022). This tendency of farmers to go non-agricultural will also reduce their investment in agricultural means of production, and they tend to use machinery to replace labor input (Qing et al., 2013). In this study, cultivated land's *per capita* area is generally higher than in other regions of China. If there is a cultivated land transfer situation, the farmer's cultivated land area will increase to a higher level, which may take a considerable farm income. Therefore, the non-agricultural effect of Internet use behavior may disappear, which means it cannot promote the development of crop rotation. The general aging problem and lagging industrial development in the study area may also make this path only exist in the younger group. In other words, the older group has difficulty expanding off-farm income through the Internet, while the younger group has more opportunities to increase off-farm income.

1 In Heilongjiang Province, the average subsidy for crop rotation is about 150 yuan per mu, which is lower than the soybean producer subsidy (about 250 yuan) and higher than the cultivated land protection subsidy (about 60 yuan).

Based on the above analysis, this research proposes the following research hypothesis:

> *Hypothesis 1*: Cultivated land transfer can promote crop rotation, which is more significant in the transition zone. Moreover, cultivated land transfer with a two-year term can promote crop rotation over 1 year.
>
> *Hypothesis 2*: Internet use promotes crop rotation, particularly in the transition zone and younger age groups.
>
> *Hypothesis 3*: There is an interactive effect between cultivated land transfer and Internet use. There was a negative moderating effect in the younger group and a positive moderating influence in the older group.

3. Materials and methods

3.1. Data description

The data in this research were obtained from a social questionnaire survey of farmers conducted in 18 towns in 3 counties in Heilongjiang Province in August 2022. Based on the characteristics of the accumulation temperature conditions, the three counties are part of the same annual agricultural maturity zone. Baiquan County has the lowest accumulation temperature, with an average daily accumulated temperature suitable for soy farming of 2,300 ~ 2,500°C·d. Wangkui County has a medium value (2,300 ~ 2,700°C·d), is suitable for maize or soybean cultivation, and is a transition zone between maize and soybean cultivation areas. Or Jixian County has the highest average with 2,500 ~ 2,700°C·d, suitable for maize cultivation. The average daily accumulated temperature in Jixian County is 2,500 ~ 2,700°C·d, which is suitable for maize cultivation. The research was conducted through face-to-face interviews between the researcher and the farmers, and the researcher filled out the questionnaires on-site. The interviewees are decision-makers within agricultural households who engage in agricultural production. They determine which crops to plant, the types of seeds and pesticides to use, which agricultural machinery services to employ, and so on. In our investigation, we are solely concerned with whether they are decision-makers, rather than their gender or age.

As shown in Table 1, the collected questionnaires were screened, and 489 valid questionnaires were obtained, including 148, 149, and 192 questionnaires in Baiquan, Jixian, and Wangkui Counties.

3.2. Model setting

In this research, the ordered logistic regression model was used to estimate the impact of cultivated land transfer and Internet use on farmers' crop rotation. The probability function is:

$$p\left(Y_L = j / x_i\right) = \frac{1}{1 + \exp\left(-\left(\alpha + \sum_{i=1}^{n} \beta_i x_i\right)\right)} \quad (1)$$

For instance, let the dependent variable Y_L represent the crop rotation method adopted by the respondents, where $Y_L = 1$ indicates the start of crop rotation, $Y_L = -1$ indicates the cessation of crop rotation, and $Y_L = 0$ represents other cases. Let x_i denote the i-th factor that affects crop rotation. The ordinal logistic regression model can be defined as follows:

$$\log it\left(P_j\right) = \ln\left[\frac{P\left(y \le j / x\right)}{1 - P\left(y \le j / x\right)}\right] = -\alpha_j + \sum_{i=1}^{n} \beta_i x_i \quad (2)$$

Here, P represents the probability of whether the interviewees rotate, and β_i represents the coefficient of the model's influencing factor x_i. When the coefficient β of the influencing factor is positive, it indicates that as the value of x increases, the potential variable Y_L will also increase, meaning that the probability of the dependent variable Y_L taking a higher level increases; when β is negative, it is the opposite.

Considering that some control variables may be missing, we add a dummy variable of the towns to which the farming household belongs to Eq. 2 above. The model is as follows:

$$\log it\left(P_j\right) = -\alpha_j + \beta_1 Trans1_i + \beta_2 Trans2_i + \beta_3 P_i + \sum_{i=4}^{n} \beta_i x_i + \gamma_{town}\phi_{town} + \varepsilon_i \quad (3)$$

where Φ_{town} is the towns dummy variable, γ_{town} is the corresponding coefficient. Other symbols have the same meaning as in Eq. 2. The ordinal logistic regression model with the inclusion of the "town" dummy variable fixes the region effect at the township scale.

To examine the interaction effect between cultivated land transfer and Internet use, we tried to build an econometric model based on Eq. 3 by adding the interaction term of cultivated land transfer and Internet use as follows.

$$\log it\left(P_j\right) = -\alpha_j + \beta_1 Trans1_i + \beta_2 Trans2_i + \beta_3 P_i + \beta_4 Trans2_i \times P_i + \sum_{i=5}^{n} \beta_i x_i + \gamma_{town}\phi_{town} + \varepsilon_i \quad (4)$$

where $Trans2 \times P$ is the interaction term with cultivated land transfer and internet use, and β_4 is the corresponding coefficient. Other symbols have the same meaning as in Eq. 2.

As for the regulation effect of age, we explored it in the form of group regression. The aging phenomenon among farmers in the research area is very serious, and it may be difficult to obtain unexpected results using the form of interaction terms. Specifically, we divided the sample into two groups based on the sample mean, the older group of age greater than or equal to 55 years old, and the younger group of age less than 55 years old.

TABLE 1 Description of the social survey information.

Counties	Location	Main crop type	Towns	Number	Date
Baiquan County	Central Songnen Plain	Soybean	Shangsheng, Shizhong, Xinsheng, Xingguo, Xinghua, Xiongnong	148	August 2022
Jixian County	West Sanjiang Plain	Maize	Fengle, Fuli, Jixian, Yong'an	149	August 2022
Wangkui County	Eastern Songnen Plain	Soybean and maize	Dengta, dongjiao, dongjiao, huiqi manchu, huojiang, lingshan manchu, xianfeng	192	August 2022

3.3. Variable selection

The explained variable. Since the Chinese government started the pilot work of crop rotation in 2016, whether farmers started crop rotation after 2016 was taken as the explained variable in this paper. We took the state of the crop rotation before 2016 as the original state and focused mainly on changes in farmers' crop rotation behavior after 2016. There are two types of such changes: those that start the crop rotation, which is the change we most want to see, and those that stop, which is the change we least want to see. The worst case scenario, where the farmers stay in the same original state, is also better than if the farmer has stopped the rotation. If farmers did not crop rotate before 2016 but started it after 2016, the value is 1. A value of −1 is assigned for crop rotation before 2016 but stops after 2016. Otherwise, it's 0. Therefore, the explained variable is an ordered categorical variable. As its value increasing, the farmer's crop rotation behavior is more positive.

Core explanatory variables. The core explanatory variables include two, namely, cultivated land transfer and Internet use. Based on relevant studies, this research selects the period of farmers' transfer into cultivated land (Gao et al., 2019; Zhou et al., 2023) and whether they use WeChat software as the core explanatory variable (Liwei, 2019; Min et al., 2021). WeChat is an instant messaging software developed by Tencent, just like WhatsApp, which also has functions such as payment and video, and has been widely used in rural China and become an important tool for rural information dissemination and community governance (Liwei, 2019; Yilan, 2019). By asking farmers, "If you transfer in someone else's cultivated land, how long is the transfer period?." To obtain information about the cultivated land transfer period, assign values to variables according to the corresponding time. The information about whether farmers use the Internet is obtained by asking them "whether you use WeChat and other software in daily life." If they do, the value is assigned as 1. Otherwise, it's 0.

Control variables. Context-aware by the findings of scientific studies (Zhaoda and Zhigang, 2021), this research selects control variables from three aspects: individual farmer characteristics (Chalak et al., 2017; Khataza et al., 2018; Derrouch et al., 2020), household characteristics (Yonghong and Hongyun, 2012; Teklewold et al., 2013; Yang and Sang, 2020; Guo et al., 2022), and agricultural operation characteristics (Hung et al., 2007; Grabowski and Kerr, 2014; Yang et al., 2022), including factors such as age, position, type of farming household, and area of cultivated land. Some of the missing values were filled in as the mean value for the village. Specific variable assignments and descriptive statistics are shown in Table 2.

3.4. Correlation analysis

Before exploring their causality, we should first confirm that they are directly correlated. And we hope that the proportion of "Stop crop rotation" will decrease, not increase. As shown in the cross table, Table 3, in a sample of "one-year cultivated land transfer period," the rate of "Stop crop rotation" grown from 7.39 to 8.88%, and "Start crop rotation" grown from 15.65 to 26.64%. In the sample of "two-year cultivated land transfer period" and "Internet use," the rate of "Stop crop rotation" all decrease, and "Start crop rotation" increase. This situation indicates a positive correlation between cultivated land transfer, internet usage, and crop rotation, with the two-year cultivated land transfer showing a more pronounced correlation. This statistical correlation suggests that we should pay more attention to its internal causal relationship.

4. Results

4.1. Baseline regression

The baseline regressions (Table 4) were conducted by adding each variable according to model (2): Model1 is the result of adding only the core explanatory variables. Model2, Model3, and Model 4 are the estimated results of adding external factors, individual factors, and business characteristics, respectively. Then, Model5 is the result of adding all control variables. The variance inflation factor value is less than 2 in each model, which strongly excludes the effect of cointegration problems.In Model 1 to Model 5, the two-year cultivated land transfer is all significantly positive at a statistical level of at least 10%, while the internet usage variable is 5%.

Combining the models' estimation results, the variable representing the cultivated land transfer, Transfer2, basically shows a more significantly positive contribution. The coefficient on the Internet use variable was incredibly positive in all models. Although positive, the coefficient on the Transfer1 variable was not significant in all models. This result means that both cultivated land transfers and Internet use contribute to farmers' crop rotation decisions. In this case, hypotheses 1 and 2 are partially confirmed. Comparing the coefficients and significance of the Transfer1 and Transfer2

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TABLE 2 Descriptive statistics of main variables.

Statistic	Define	Num	Mean	St. Dev.
CR	Crop rotation behavior after 2016; Start crop rotation =1; Stop crop rotation = −1; Otherwise =0	489	0.13	0.53
Transfer1	One-year cultivated land transfer-in; Yes =1, no =0	489	0.53	0.5
Transfer2	Two-year cultivated land transfer-in; yes =1, no =0	489	0.05	0.22
Internet use	Internet use; Yes =1, no =0	489	0.52	0.5
GDD	Transition zone; Wangkui County =1, other =0	489	0.39	0.49
sex	Sex; male =1, female =0	489	0.88	0.33
age	age	489	54.64	9.8
health	Health status; good =1, generally =2, poor =3, very bad =4	489	1.14	0.42
culture	Education level; very little literacy or literacy =1; primary school =2, middle school =3, technical secondary school or high school =4, junior college, undergraduate degree and above =5	489	2.38	0.72
labor	Number of the labor (person)	489	2.27	1.78
workout	Migrant work experience;In the province =0, outside the province =1	489	0.45	0.5
govjob	Whether to be a village committee cadre; Yes =1, no =0	489	0.08	0.28
rualincomeperc	The proportion of agricultural income in the total household income; 0–20% =1; 20–50% = 2; 50–80% = 3; 80–100% = 4	489	3.42	0.90
partymem	Member of the Communist Party of China; Yes =1, no =0	489	0.05	0.21
farmtype	Types of farmers;Normal farmers = 1，Big farmer = 2(>100 mu)	489	1.46	0.56
ALmaxarea	Maximum cultivated land area (mu)	489	27.88	68.58
Cognition	Crop Rotation can increase the perception of yield; complete disagreement =1, great disagreement =2, uncertainty =3, comparative consent =4, complete consent =5	489	4.52	0.66

variables shows that a two-year cultivated land transfer period is more likely to encourage crop rotation than a one-year cultivated land transfer. Hence, hypothesis 1 is further corroborated. From Model1 to Model5, the model's effect on the variables has grown. Still, the importance and sign of the coefficients of this study's primary explanatory variables have largely remained the same. The basic robustness of the regression results is illustrated from the perspective of model construction.

TABLE 3 The correlation of cultivated land transfer, Internet use and crop rotation.

CR	Transfer1		Transfer2		Internet use	
	0	1	0	1	0	1
Stop crop rotation (−1)	17(7.39%)	23(8.88%)	39(8.42%)	1(3.85%)	23(9.83%)	17(6.67%)
Otherwise (0)	177(76.96%)	167(64.48%)	327(70.63%)	17(65.38%)	174(74.36%)	170(66.67%)
Start crop rotation (1)	36(15.65%)	69(26.64%)	97(20.95%)	8(30.77%)	37(15.81%)	68(26.67%)

TABLE 4 Baseline Regression results.

	Model1	Model2	Model3	Model4	Model5
	Only core explanatory variables	Add individual farmer characteristics	Add household characteristics	Add agricultural operation characteristics	All controls
Transfer1	0.2278 (0.2852)	0.2849 (0.2974)	0.2122 (0.2820)	0.2000 (0.2756)	0.2309 (0.2928)
Transfer2	1.0853** (0.5465)	1.0716* (0.6050)	1.1061** (0.5504)	1.0472** (0.5273)	1.0382* (0.5792)
Internet use	0.4772** (0.1860)	0.5048** (0.1977)	0.4920*** (0.1834)	0.4580** (0.1938)	0.4900** (0.2043)
age		0.0031 (0.0168)			0.0030 (0.0165)
Cognition		−0.3701** (0.1679)			−0.3769** (0.1692)
culture		−0.1817 (0.1876)			−0.1863 (0.1821)
govjob		−0.0345 (0.3408)			−0.0452 (0.3129)
labor			−0.0201 (0.0391)		−0.0258 (0.0395)
coomem			0.1187 (0.3867)		0.0741 (0.3433)
rualincomeperc			0.1432 (0.1395)		0.1217 (0.1441)
farmtype				0.1446 (0.2089)	0.1883 (0.2088)
ALmaxarea				−0.0013 (0.0017)	−0.0011 (0.0018)
Fixed effect	Town	Town	Town	Town	Town
Num. Obs.	489	489	489	489	489

*, **, and *** are significant at the levels of 0.1, 0.05, and 0.01, respectively; Adopt robust standard error, and the standard error is in parentheses.

4.2. Robustness test

To further verify the reliability of the baseline regression results, this research uses the method of replacing the explanatory variables and the core explanatory variables to verify the robustness of the baseline regression results. "Whether you can shop online" was used as a proxy variable for Internet use behavior. The difference between this variable and the original core variable is that the replaced core explanatory variable has stricter requirements for the depth of internet use. The explanatory variable was replaced with "whether to continue crop rotation after 2016," with crop rotation after 2016 being assigned a value of 1. Otherwise, it is 0. The difference between this variable and the original explanatory variable is that the new explanatory variable only emphasizes crop rotation after 2016 and does not focus on whether crop rotation occurred before 2016. The above variables were brought into the model (2) and estimated. The results are presented in Table 5.

Overall, the significant contributions of two-year cropland transfer and Internet use remain. The coefficient on the two-year cropland transfer remains important, at least at the 0.1 level, in all models except model 8. The coefficient on the Internet use variable is not only lightly significant in Model9, at least at the 0.1 level in all other cases.

These results confirm that the results of the baseline regression discussed above are robust and plausible. Overall, the estimates from the robustness tests remain largely consistent with the theoretical analysis and the baseline regression estimates. Parts of Hypothesis 1 and Hypothesis 2 are once again corroborated.

Endogeneity. First of all, our study area is representative of a variety of natural conditions, and the subjects (farmers) were randomly selected within each county. Therefore, the selection bias can be excluded in this study. Secondly, as we introduced in the introduction part, the study area are facing with almost the same problems of aging farmers and low literacy. And as Table 2 shown, the crop rotation has a obvious different statistical distribution than cultivated land transfer and Internet use. In addition, We also control individual farmer characteristics, household characteristics and agricultural operation characteristics in all regressions. The results of the "4.4. Further discussion" part further support our view. So, sample self-selection will not seriously affect this study.

However, to ensure that the baseline regression results are not affected by the sample self-selection problem, we utilize the PSM method for causal inference between variables. Then take "Transfer1," "Transfer2," and "Internet use" as processing variables respectively, and the obtained ATT effect is as follow in Table 6. It can be seen that the impact of the two-year cropland transfer and Internet use is still

TABLE 5 Results of the robust test.

	Model6 Replace X	Model7 Replace X	Model8 Replace Y	Model9 Replace Y
Transfer1	0.2639 (0.2270)	0.4542** (0.2056)	−0.3711 (0.2793)	−0.1019 (0.1994)
Transfer2	0.9964** (0.4869)	0.7941* (0.4238)	1.0927 (1.1580)	2.7004*** (1.0267)
Internet use	0.6032** (0.2449)	0.5302** (0.2260)	0.5483* (0.2955)	0.3532* (0.2172)
Controls	Yes	No	Yes	No
Fixed effect	Town	Town	Town	Town
Num.Obs.	489	489	489	489

*, **, *** denote significance at the 0.1, 0.05, and 0.01 levels, respectively; robust standard errors clustering to town. The value of p for the coefficient on the Internet use variable in Model9 is 0.1039, considered significant at the 0.1 level.

TABLE 6 Results of the robust test.

	K =1	Caliper (0.05)	Kernel
Transfer1	0.11 (1.50)	0.11 (1.50)	0.06 (1.14)
Transfer2	0.27* (1.84)	0.28** (1.90)	0.18 (1.58)
Internet use	0.20** (2.30)	0.12** (2.31)	0.18*** (2.64)

t-value is in parentheses.

relatively significant. This shows that the above results based on benchmark regression are reliable.

4.3. Mechanism analysis

Taking into account the characteristics of the study area and the analysis results presented above, we considered it necessary to conduct a first-group regression from a regional perspective to observe the impact of the core explanatory variables in different regions. Secondly, agricultural operators in the study area are heavily aged, with an average age of 55 years old. Farmers' recognized level of crop rotation and the digital divide are closely related to their age. It was, therefore, necessary to run regressions by age grouping to see the impact of the core explanatory variables across age groups. The estimated results are shown in Table 7.

Model11 and Model12 show that the impacts of cultivated land transfer and internet use are more pronounced in the transition zone areas, with the variable coefficients exhibiting satisfactory statistical significance.[2] In the same sense, Model13 and Model14 show that a two-year land transfer significantly promotes arable crop rotation for the older group (age > 55). For the younger group (age <= 55), the effect of Internet use is more significant. Possible explanations for this are that in the transition zone areas, where the difference in returns between maize and soybean cultivation is relatively small and the proportion of previous rotations is not high, farmer rotations are relatively more influenced by other factors. In terms of age, older farmers are more aware of crop rotation and tend to undertake it when land rights are relatively more stable. On the other hand, although older farmers can use the mobile Internet, the information literacy gap is challenging to fill. Conversely, younger groups are more able to obtain adequate information and incentives to progress with crop rotation through their Internet use.

We also observe whether the two core explanatory variables have the ability to influence each other and create an interactive effect. We, therefore, test hypothesis 3 by including an interaction term between the cultivated land transfer variable and the Internet use variable. The results of the model estimation are shown in Table 8. Because of the intractable cointegration problem in Model18, we used group regressions to recheck. The results are shown in Table 9.

In Table 8, the interaction term variable only showed statistical significance in the transition zone and the older group. In Table 9, the coefficient on the Transfer2 variable is more significant for the subgroup of the older group that uses the Internet than for the group that does not use it. A possible explanation is that the region of interest in this research has a relatively high share of primary industries and a general lack of non-farm employment among farm households. Internet use can increase farm households' income sources to some extent (Xiaona and Xuekai, 2020; Fang et al., 2022), improving their income structure and raising their household income levels. Farming households with non-farm income no longer rely primarily on farmland output. The significant input–output efficiency difference between the agricultural and non-agricultural sectors means they may not put more effort into farming when transferring farmland to them. They are more inclined to use agricultural machinery for labor substitution (Kung, 2002)through crop-scale cultivation to improve input–output efficiency. They are, therefore, less likely to undertake crop rotation than farm-based farmers. However, this effect does not apply to older groups. Because of their age, it is difficult for them to benefit from using the Internet to take up non-farm jobs and find non-farm sources of income. So the absence of this pathway would result in this group being tied to agricultural production and having the relative energy to undertake crop rotation. Based on these descriptions and results, hypothesis 3 was not entirely substantiated.

Furthermore, we discuss heterogeneity in terms of the presence or absence of the labor force and literacy. The results (not reported) show that the effects of cultivated land transfer and Internet use to promote crop rotation are more prevalent in the group of farmers with labor experience, the group with primary school education or less, and the group with less than 80% of farm income. One possible explanation is that farmers who do not have migrant work experience and have less education are more aware of crop rotation and are more likely to do it because of cultivated land transfers and the Internet. This situation also confirms that farmers are less inclined to rotate their crops when they have non-farm jobs or non-farm sources of income.

5. Discussion

This research explores the specific effects of cultivated land transfer and Internet use on crop rotation and further examines the heterogeneity across regions and farmer groups. Our results show that

2 The t-statistic of the exponent for the internet usage variable is 1.6479, very close to the critical value at the 10% significance level. This study considers this test result to be supportive of the conclusions drawn.

TABLE 7 Regression results by regions and age groups.

	Model10	Model11	Model12	Model13	Model14
	All Samples	No-transition zone	Transition zone	Age>55	Age<=55
Transfer1	0.2309 (0.2928)	−0.1965 (0.3572)	0.9385*** (0.2216)	0.2938 (0.3533)	0.1076 (0.3772)
Transfer2	1.0382* (0.5792)	0.6316 (0.6624)	2.6896*** (0.6976)	2.4430*** (0.6562)	0.1640 (0.7914)
Internet use	0.4900** (0.2043)	0.4245* (0.2457)	0.6010 (0.3657)	0.3281 (0.4545)	0.7877*** (0.2975)
Controls	Yes	Yes	Yes	Yes	Yes
Fixed effect	Town	Town	Town	Town	Town
Num.Obs.	489	297	192	221	268

*, **, and *** are significant at the levels of 0.1, 0.05, and 0.01, respectively; Adopt robust standard error.

TABLE 8 Test of the interaction effect between cultivated land transfer and Internet use.

	Model15	Model16	Model17	Model18	Model19
	All samples	No-transition zone	Transition zone	Age>55	Age<= 55
Transfer1	0.2259 (0.2882)	−0.2049 (0.3591)	0.9179*** (0.1822)	0.3609 (0.3679)	0.1102 (0.3918)
Transfer2	1.4403** (0.5697)	0.9379* (0.4971)	10.0891*** (0.6612)	2.0328*** (0.6567)	−0.0680 (0.4001)
Internet use	0.5221** (0.2285)	0.4581 (0.3032)	0.6165* (0.3643)	0.2619 (0.4694)	0.7770** (0.3032)
Transfer2 × Internet use	−0.8725 (0.8605)	−0.6129 (1.0706)	−8.8936*** (0.6607)	14.8061*** (0.000002)	0.3002 (0.9234)
Controls	Yes	Yes	Yes	Yes	Yes
Fixed effect	Town	Town	Town	Town	Town
Num.Obs.	489	297	192	221	268

*, **, and *** are significant at the levels of 0.1, 0.05, and 0.01, respectively; Adopt robust standard error.

both cultivated land transfer and Internet use promote crop rotation, with the effect of cultivated land transfer being stronger than Internet use behavior. Then, a two-year period of cultivated land transfer significantly facilitates crop rotation, which is more significant than a one-year cultivated land transfer. This result is consistent with the results of related studies (Gao et al., 2019; Bo and Ruimei, 2021). As significant externalities characterize crop rotation in space and time, the stability of farming rights helps increase farmers' willingness to rotate their crops. The empirical results of this research also show that Internet use behavior can significantly promote crop rotation among farmers. The analysis shows that farmers can use the Internet to get more accurate and useful technical and policy information about crop rotation. This situation makes farmers more likely to rotate their crops. This context is consistent with the findings of related studies (Zhou et al., 2023).

It is important to note that some studies have found that the decentralization of cultivated land can contribute to the diversification of agricultural production (Ciaian et al., 2018; Qiu et al., 2020). In contrast, this research concludes that centralized, stable management can contribute to diversification. The former conclusion presupposes that local farmers rely solely on agricultural production to meet their subsistence needs or to develop urban agriculture, both of which are far from the reality of our study area. This context exists because the study area is one of China's major commodity grain bases and is responsible for the bulk of grain production. That is why the above-perceived differences arise.

The research also finds that cultivated land transfer and Internet use have differential impacts across regions and age groups. The impact of crop rotation was more significant in the transition zone regions and less statistically significant in the non-transition zone regions. This discussion is innovative in this research because it incorporates natural conditions into studying crop rotation decision mechanisms. However, studies have focused on the differential effects of cumulative temperature conditions on farmers' willingness to be paid (Xiaozhong et al., 2017; Haijiang et al., 2019). But there is not enough empirical talk looking at mechanisms of action. Our findings also revealed that the role of Internet use behavior was most prevalent among younger groups. Our results also highlighted that the role of Internet use behavior was mainly among the younger groups. These results may be because younger farmers can obtain adequate information from Internet use; they show that the digital divide exists among different age groups in rural areas. The multi-level digital divide between rural and urban areas in the digital economy is a phenomenon that has answered this discussion (Yi and Jie, 2021).

This study also has three major shortcomings. First, this research argues that the temporal–spatial externality of crop rotation can be solved by means of cultivated land transfer. But this problem can also be solved with farmers' cooperation. Some studies have found that farmers' social network relationships also affect the adoption of conservation tillage techniques (Schneider et al., 2012; DeDecker et al., 2022). This issue appears in this study and should be considered in future studies. Second, farmer aging is general in the study area and directly affects agricultural production's labor input. In order to solve this problem, the local government is also actively developing social services for agricultural production. This service is also expected to solve the age factor's restriction on cultivated land use. However,

TABLE 9 Group regression based on age and Internet use behavior.

	Model20	Model21	Model22	Model23
	Internet use=0 and age>55	Internet use=1 and age>55	Internet use=0 and age<=60	Internet use =1 and age<=60
Transfer1	0.6736 (0.4335)	0.0306 (0.7651)	−0.5521 (0.4490)	0.5672 (0.4753)
Transfer2	3.3584*** (0.8850)	28.3671*** (9e-10)	0.8115 (1.1798)	0.2274 (1.0639)
Controls	Yes	Yes	Yes	Yes
Fixed effect	Town	Town	Town	Town
Num.Obs.	155	66	123	189

*, **, and *** are significant at the levels of 0.1, 0.05, and 0.01, respectively; Adopt robust standard error. In order to meet the sample requirements of regression, we adjusted the age in Model22 and Model23 to 60 years old.

we have not obtained sufficient information due to the survey limitations, such as the data collection time. Consequently, it is not convenient to easily achieve the above goals. We believe that future research can be further discussed from the perspective of society, which is a new idea in rural aging. Third, in this study, we consider the use of the internet as an important means to enhance farmers' cognitive level. Therefore, the causal relationship between internet use and crop rotation that we have revealed is an indirect one, and further research can verify it through more direct means. Particularly, with the current intensification of international food trade risks, price signals can be disseminated more rapidly through the internet. Fluctuations in international food prices may trigger changes in farmers' cultivation behaviors.

6. Conclusion

This study finds that cultivated land transfer and Internet use promote crop rotation, mainly in the maize-soybean transition zone. Cultivated land transfer has a more substantial effect than Internet use. A two-year cultivated land transfer enables crop rotation more significantly than a one-year cultivated land transfer. The analysis of the mechanisms shows that the promotion of cultivated land transfer is mainly in the older age groups, while the promotion of Internet use is primarily in the younger age groups. The role of crop rotation does not change with the farmer's age, while the effect of Internet use decreases with it. The combined impact of cultivated land transfer and Internet use is not conducive to crop rotation in the transition zone but can facilitate crop rotation in the older age groups. The main contribution of this study is to reveal that there is not only age group heterogeneity but also region heterogeneity in the effects of land tenure and cognitive level in the farmer's decision-making mechanisms.

The findings of this study have positive policy implications.First, crop rotation in the maize-soybean transition zone has much scope for expansion and is vulnerable to external forces. This context suggests encouraging crop rotation in the maize and soybean transition zones. In this region, the economic yield gap between maize and soybeans are smaller, and the climate suitability is higher, giving farmers economic incentives to carry out crop rotation driven by policies. Second, stable land rights help farmers carry out crop rotations for long periods, and highly constrained cultivated land transfer should be encouraged. Particular attention should also be paid to the concentration of cultivated land transfer to mitigate the loss of spatial externalities from crop rotation. At the same time, the government should strengthen the formalization of the cultivated land transfer contract in rural areas to protect the legitimate rights of farmers on both sides. We should pay special attention to the needs of the older farmers and provide them with more comprehensive intermediary services for cultivated land transfer by utilizing socialized agricultural production and service organizations. Thirdly, the digitalization of rural areas should be strengthened to improve the information literacy of farmers, alleviate the urban–rural digital divide, and provide differentiated information support for different groups of farmers. For young farmers, in particular, digital information is more easily disseminated, which means that digital information support contributes to the intergenerational sustainability of agricultural production. As the world's development becomes increasingly digital, it's necessary to consider rural areas and agricultural production and use digital means to bridge the information gap between urban and rural areas.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CL: conceptualization, data curation, formal analysis, investigation, ethodology, and writing—original draft. GD: data curation, investigation, funding acquisition and project administration. CL and BF: writing—review & editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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