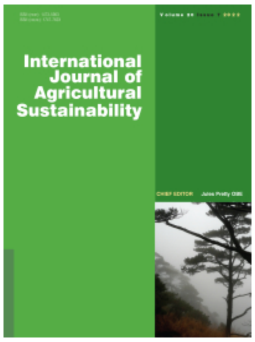

International Journal of Agricultural Sustainability

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tags20

How channels of knowledge acquisition affect farmers' adoption of green agricultural technologies: evidence from Hubei province, China

Xuan Wang, Dušan Drabik & Junbiao Zhang

To cite this article: Xuan Wang, Dušan Drabik & Junbiao Zhang (2023) How channels of knowledge acquisition affect farmers' adoption of green agricultural technologies: evidence from Hubei province, China, International Journal of Agricultural Sustainability, 21:1, 2270254, DOI: 10.1080/14735903.2023.2270254

To link to this article: https://doi.org/10.1080/14735903.2023.2270254

Published online: 01 Nov 2023.

INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY
2023, VOL. 21, NO. 1, 2270254
https://doi.org/10.1080/14735903.2023.2270254

How channels of knowledge acquisition affect farmers' adoption of green agricultural technologies: evidence from Hubei province, China

Xuan Wang[a], Dušan Drabik[b,c] and Junbiao Zhang[d,e]

[a]College of Economics & Management, Huazhong Agricultural University, Wuhan, People's Republic of China; [b]Agricultural Economics and Rural Policy Group, Wageningen University, Wageningen, The Netherlands; [c]Department of Trade and Accounting, Czech University of Life Sciences in Prague, Czech Republic; [d]College of Economics and Management, Zhejiang A&F University, Hangzhou, People's Republic of China; [e]Zhejiang Rural Revitalization Research Institute, Hangzhou, People's Republic of China

ABSTRACT

Farmers' adoption of green agricultural technologies (GATs) could reduce the negative environmental impacts of traditional agriculture in China. Despite the benefits of GATs, their adoption rate has not been high. While previous studies have examined the information and communication technologies that influence the adoption of GATs, most have selected only one of the GATs and have not distinguished between public and private channels of knowledge acquisition. In this paper, based on a sample of 732 rural households from Hubei Province, we used a negative binomial model to examine the role of knowledge acquisition channels on GATs adoption. Overall, we found that radio and the government (through its face-to-face channels) are positively associated with farmers' adoption of GATs; however, farmers adopted more GATs when they had acquired knowledge from the government than from radio. A possible explanation and a policy implication is that direct communication with farmers and practical demonstration of the benefits of GATs are preferred to passive reception of information.

ARTICLE HISTORY
Received 20 January 2023
Accepted 8 October 2023

KEYWORDS
Channels of knowledge acquisition; green agricultural technologies; negative binomial model; China

1. Introduction

The dominance of conventional farming since the 1960s has brought about not only yield increases but generated also multiple problems. For example, the overuse of chemical fertilizers and pesticides has caused a soil productivity decline and large emissions of greenhouse gases which led to climate change, especially in developing countries (Hansen, Alrøe, & Kristensen, 2001; Antle & Diagana, 2003; FAO, 2017).[1] This also holds true for China in the "boosting" stage of the country's agricultural sector in the 1970s – 1990s, characterized by high yields and efficiency, mechanization and chemicalization, and serious environmental pollution (Liu, 2023). The consequences persist to date as documented, for example, by the National Soil Pollution Status Survey Bulletin released in 2014, according to which the quality of arable soil in China is worrying – 16.1% of arable soil spots exceed the Chinese pollution standard, mainly due to excessive use of chemical fertilizers and pesticides (Xie et al., 2019). Therefore, under limited natural resources, the traditional production methods are not conducive to the long-term sustainable development of agriculture in China.

To help solve this problem, China's 14th Five-Year Plan has emphasized the need to strengthen agricultural environmental management and promote green agricultural development. The main objectives of the latter include more economical and efficient use of

CONTACT Junbiao Zhang zhangjb513@126.com College of Economics and Management, Zhejiang A&F University, Room 319, Experimental Building of Zhejiang A&F University, Hangzhou, Zhejiang 311300, People's Republic of China

resources, cleaner production, more stable ecosystems, and significantly improved green supply capacity. Green production is the core of green transformation in agriculture. Given the limited carrying capacity of soil, promoting green production in agriculture is expected to help China promote sustainable development of agricultural systems and achieve greenhouse gas emission reduction targets in the sector (Zhang, Bai, Sun, Xu, & He, 2021).

The requirements of the China's government for green production in agriculture target water control, land quality conservation and improvement, fertilizer and pesticide reduction and efficiency enhancement, non-point source pollution control, and the use of waste (He et al., 2021). These have led to the development of green agricultural technologies (GATs), that is, technologies that could reduce pollution and prevent resource destruction in agriculture (Barbosa et al., 2015; Huisingh et al., 2015). Examples of available GATs in China include scientific use of pesticides, straw returning, planting green manure, and livestock and poultry manure resource use. Among them, straw returning yields a double dividend, as it reduces air pollution by not emitting CO_2 emissions from burning the straw and increases the soil fertility of the farmland. Green manure is designed to replace chemical fertilizers, which can contribute to achieving the goals of resource conservation (reduction in the use of fertilizers) and environmental protection (elimination of soil pollution) (Li et al., 2020).

Promoting GATs among farmers and enhancing their adoption is also essential in achieving green agricultural production. Information and knowledge about GATs are generally diffused through information and communication technologies (ICTs) or face-to-face interaction. At present, there are three main sources of face-to-face interactions that raise awareness of GATs in China: government-related organizations, enterprises, and individual households. As there are different sources of information about GATs, it might be difficult for farmers to judge the effectiveness of implementing individual GATs, especially when quantifiable short-term benefits might not be obvious. This could ultimately lead to low participation of farmers in adopting GATs.

The objective of our study is, therefore, to investigate the extent to which selected channels of knowledge acquisition determine the number of adopted GATs. More specifically, using the information from a survey consisting of 732 households carried out in Hubei province, China in 2021, we determine which GATs have been adopted most and what spectrum of information channels the farmers used in making their decision about adopting GATs. Knowing which information factor(s) are most associated with GATs' adoption can aid policymakers in promoting information campaigns targeted at accelerating green agricultural development.

A few studies have looked into whether every ICT affects farmers' GATs adoption (Coromaldi et al., 2015; Vasudevan, 2022; Zhao et al., 2021). Nevertheless, how ICTs affect the number of adopted GATs by farmers remains to be verified. Our contribution to the existing literature lies in investigating the strength of the link between different channels through which farmers learn about GATs and their adoption. This approach also differs from the previous studies that looked at how household or soil characteristics determine whether or not a GAT will be adopted. In addition, we study if the means of information communication technologies are more effective in affecting technology adoption than personal communication.

2. Literature review and conceptual framework

2.1. Adoption of GATs

GATs aim to alleviate pollution, reduce resource input, and improve agricultural productivity of farmers (Dong, Yang, Yu, & Feng, 2018; Liu, Chen, & Li, 2019; Li, Wang, Zhao, Chen, & Wu, 2020). They can be adopted throughout the entire production process (e.g. organic fertilizers, biological control of plant diseases and pests), including preproduction (e.g. a new plant variety), and postproduction stages (e.g. straw recycling technology) (Wang, Wang, Liu, & Wu, 2020). The diffusion of these technologies provides the foundation and guarantee of green agriculture development (Bukchin & Kerret, 2018).

In recent years, developing countries have attached great importance to the development of GATs, which has promoted the creation of a green environment (Rupani et al., 2019). As a result of the numerous sustainable benefits of green agriculture technologies, many governments and organizations have taken measures to promote their diffusion and adoption. For instance, the World Vegetable Centre has promoted various green technologies in Tanzania through Africa RISING[2] and other initiatives (Ochieng et al., 2021). African governments and donors have developed policies and programmes related to input subsidies, government-provided services, and the establishment of input and commodity marketing parastatals (Nin-Pratt & McBride, 2014).[3]

Even if measures related to promoting GATs adoption are useful, there are different factors that determine their effectiveness (Chen et al., 2020). Scholars have conducted many studies from different perspectives to research the diffusion and adoption of GATs. First, the impact of farmers' individual characteristics on green agriculture technology adoption has been studied. For example, better-educated and more experienced farmers tend to adopt knowledge-intensive technologies faster in traditional cultivation practice (Kabunga, Dubois, & Qaim, 2012). Second, with regard to the impact of household resource endowment on the adoption of GATs, Wainaina et al. (2016) found that soil condition matters a lot in the adoption of natural resource management technologies, and Feder et al. (1985) found that distance to markets influenced technology adoption. Third, regarding the impact of psychological factors on the adoption of GATs, Zeng et al. (2020) incorporated external incentives and social norms into the norm-activation model and explored how environmental conscience, external incentives, and social norms influence the GATs adoption behaviour of rice farmers.

Unlike the studies reviewed above, we focus on the link between the channels of knowledge acquisition and the adoption of GATs. One of these channels is information communication technology.

2.2. Information and communication technology

The rapid spread of ICTs in developing countries offers a unique opportunity to transfer knowledge via private and public information systems. Ndiwalana, Scott, Batchelor, and Sumner (2010) concluded that radio and face-to-face communication are the dominant means of obtaining information in Uganda. However, growing evidence suggests that not all ICTs extension approaches are equally effective in desirable outcomes, such as enhancing farmers' knowledge, increasing technology adoption rates, or improving crop and livestock yields (Olumese et al., 2018; Tambo et al., 2019; Voss et al., 2021). There is also increasing evidence that ICTs extension approaches are not equally effective for all farmers (Spielman, Lecoutere, Makhija, & van Campenhout, 2021). As a result, governments and organizations attempt to find ways to deliver agricultural technology information efficiently to farmers (Anderson & Feder, 2007).

The ways through which local governments and organizations in China promote GATs can be grouped into traditional and new (Yin, Luo, Li, & Huang, 2018). The traditional way relies on face-to-face interaction with people (e.g. in-the-field guidance and technological training) and mass media publicity (e.g. newspaper, radio, and television) (Huang et al., 2008; Gao, Zhao, Yu, & Yang, 2020).[4]

A new GATs extension mode releases GATs-related information and solves farmers' technical problems through new media (e.g. WeChat, Weibo), which are mainly based on "internet+" technology (Li et al., 2018). Mapiye, Makombe, Molotsi, Dzama, and Mapiye (2021) also found that mobile and web-based technologies led to a surge in agricultural extension services in sub-Saharan Africa.

2.3. A conceptual framework

To develop a conceptual framework for farmers' adoption of GATs, we mainly built on behavioural theory: Rogers et al. (2014)'s theory of diffusion of information. Information is disseminated through both informal and formal sources. In developing countries, agricultural extension workers, public sector officers, progressive farmers, television, radio, newspapers, private agents, and mobile phones are the information sources most used by farmers (Mwombe, Mugivane, Adolwa, & Nderitu, 2014; Nikam, Kumar, Kingsly, & Roy, 2020). Azumah et al. (2018) also found that demonstration, farmer-to-farmer communication, and household extension methods were perceived as the most effective agricultural technology information extension methods. In this paper, channels of knowledge acquisition integrate all the ways through which farmers can obtain information about a new production practice. This can be done either indirectly (e.g. TV, radio, the internet, newspapers) (with limited to no possibility to interact with the source of information) or directly (e.g. through governmental channels, cooperatives, enterprises, or relatives), in which case experts or professional staff are typically called to disseminate information about one or several types of GATs to farmers by field demonstrations or face-to-face training and provide paper manuals. Through direct channels, farmers seem to get amounts of targeted information.

Additionally, we drew from the broad range of existing literature and empirical findings on economic and behavioural factors influencing farmers' adoption of GATs above. We concluded that farmers' decision-making with respect to the adoption of GATs is determined by four main factors: channels of knowledge acquisition, household characteristics, individual characteristics, and other external factors.

The focus here is on the role of channels of knowledge acquisition in GATs adoption. The decision by farmers to adopt GATs depends on their knowledge of the practice (Segura, Barrera, Morales, & Nazar, 2004). The relevant information on GATs should lead to their adoption: the more relevant it is, the more likely it will occur (Tey et al., 2014). Based on the above literature and analysis, we know that although different channels of knowledge acquisition deliver information to farmers, there are still gaps in diffusion effectiveness among them. Consequently, we analyzed whether and how different channels of knowledge acquisition affect the number of GATs adopted by farmers. Our conceptual framework is shown in Figure 1. Channels of knowledge acquisition diffuse the information about GATs to farmers. The information farmers receive, together with household and individual characteristics, determines the number of adopted GATs.

3. Data and methodology

3.1. Questionnaire design and data collection

3.1.1. Questionnaire design

A questionnaire was used to collect data and was first designed to include the basic status of villages, personal and family information, migrant work situation, agricultural production, revenues and expenditures, improvement of the living environment, household waste classification, the degree of informatization, energy, cognition, and social life. The draft questionnaire was then reviewed by four experts who mainly focus on agricultural resources and environmental economics. A second version was created based on the received comments, and then a pilot survey was conducted with 20 farmers in Hubei province. A further revision was made according to the feedback received from the pilot study. The final version of the questionnaire contained the basic status of villages, personal and family basic information, agricultural production, and the revenues and expenditures situation. The basic status of villages part includes the villages' basic information, such as the village terrain type and whether the village has professional farmers' cooperatives. The personal and family basic information part reflects the farmers' personal and family basic information, including personal characteristics (e.g. gender, age, and educational attainment) and family characteristics (e.g. number of family members). The agricultural production part provides farmers' production conditions (e.g. soil fertility and irrigation conditions). The revenues and expenditures situation part provides farmers' different revenues and expenditures in 2019 and 2020 (e.g. total household income).

3.1.2. Data collection

Hubei province is one of the major agricultural provinces in China, whose main crop is paddy rice and its output accounted for over 4% of China's total grain production in 2020.[5] The survey was carried out from July to August 2021 by trained

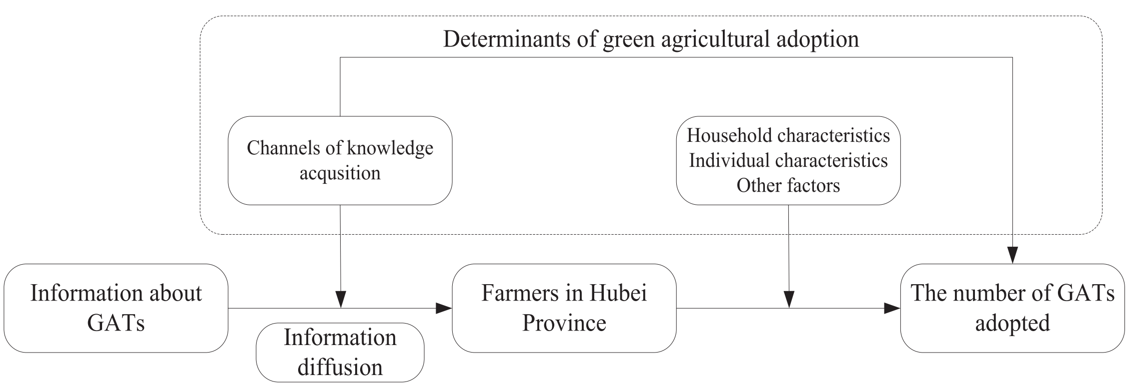

Figure 1. Conceptual Framework.

postgraduates in rural areas of Hubei province through face-to-face interviews. To ensure the validity of the collected data, the investigators were professionally trained before conducting the survey.

First, we selected six cities (Wuhan City, Xiangyang City, Qianjiang City, Honghu City, Jingshan City, Zhongxiang City) and one county (Yangxin County). Their total grain production accounted for more than 50% of Hubei's grain output in 2020. The six cities and the county cover all terrain types in Hubei province, including mountains, plains, and hills. Furthermore, in each district, we contacted the Agricultural and Rural Bureau and asked the staff to tell us about the actual development of the local rural areas. Then, we selected one to three towns that had implemented practices related to the questionnaire content from each of the six cities and the county randomly. To acquire a certain number of samples in each village, we selected one or two large-scale villages in each town, and finally, in each village, we chose the respondents randomly. In total, a sample of 811 questionnaires was collected. Due to missing values or logical errors in the responses, 79 questionnaires had to be removed. As a result, we obtained 732 valid surveys for our empirical analysis.

3.2. Basic characteristics of the sample

The proportion of men (58.2%) in our sample is seven percentage points higher than that of Hubei province (Table 1). We also calculated the average annual total household income in the sample to be 18,305 yuans, which is 12.3% higher than rural households in Hubei province in 2020 (16,306 yuans). In addition, 50.3% of the respondents' educational attainment is six years or less, followed by seven to nine years (36.2%), and only 13.5% of respondents had more than nine years of education. However, in Hubei province, only about one-third of the population received six years or fewer of education and 32.9% of the population received more than nine years of education, which indicates that our respondents were generally less educated than the overall population of Hubei province. The age of the sample farmers is dominated by 15- to 64-year-olds (68.0%), which is close to the situation in Hubei province (69.1%). However, 32% of the respondents were above 65 years of age, which is more than double that of Hubei province. Hence, the sampled farmers are older and have received less education when compared to Hubei province. We did not investigate any respondents below 15 years of age because these children are required to have compulsory education in China. As a result, they were not in our sample.

3.3. Methodology

3.3.1. Negative binomial model

The dependent variable Y in this paper, "the number of adopted green agriculture technologies", which in the questionnaire included new crop varieties, less tillage and no tillage, deep soil loosening, green manure planting, water-saving irrigation, green prevention and control, straw returning, livestock and poultry manure use, and recycling agricultural film, is a count variable that ranges from zero to nine. Its data structure belongs to a discrete distribution. Therefore, a Poisson model or negative binomial model is considered for parameter estimation.) For farmer i, Y_i is the total number of GATs available, and y_i is the number of GATs adopted by farmers. Assuming that the probability of $Y_i = y_i$ is determined by the Poisson distribution with parameter λ_i,

$$p(Y_i = y_i|x_i) = \frac{e^{-\lambda_i}\lambda_i^{yi}}{y_i!} \text{ for } y_i = 0,\ 1,\ 2,\ \ldots,\ N, \quad (1)$$

where λ_i is the Poisson arrival rate, which indicates the average number of GATs adopted, and x_i denotes the independent variables, such as personal or household characteristics. The expected value and variance of the Poisson distribution are equal

Table 1. Basic sample characteristics (N = 732).

Categories		Count	Sample	Hubei Province (in 2020)
Average annual total household income	–	732	18,305.1 yuans	16,305.9 yuans
Gender	Male	426	58.2%	51.4%
	Female	306	41.8%	48.6%
Educational attainment	< 6 years	368	50.3%	32.8%
	7–9 years	265	36.2%	34.3%
	> 9 years	99	13.5%	32.9%
Age	< 15 years	0	0	16.3%
	15–64 years	498	68.0%	69.1%
	> 64 years	234	32.0%	14.6%

to λ_i:

$$E(Y_i|x_i) = Var(Y_i|x_i) = \lambda_i. \quad (2)$$

The equivalence of the conditional mean function and the variance function is usually considered the main drawback of the Poisson model, and the negative binomial model is the most common alternative (Goto, Fujita, & Sueyoshi, 2020). For a negative binomial regression (Coleman, 1964), the logarithmic expression for the conditional expectation function is.

$$\ln \lambda_i = x_i'\beta + \varepsilon_i, \quad (3)$$

where x_i denotes the row vector of the independent variables, β is a column vector of the effect parameters, and ε_i denotes the error term.

Expression (3) can be rewritten as:

$$\lambda_i = \exp(x_i'\beta)\exp(\varepsilon_i) = u_i v_i, \quad (4)$$

where $u_i = \exp(x_i'\beta)$ is a deterministic function of x_i; $v_i = \exp(\varepsilon_i) > 0$ is a random variable. Given x_i and v_i, y_i still obeys the Poisson distribution as follows:

$$p(Y_i = y_i|x_i, v_i) = \frac{e^{-u_i v_i}(u_i v_i)^{y_i}}{y_i!} \text{ for } y_i = 0, 1, 2\ldots, N. \quad (5)$$

Based on (5), we calculated the conditional variation and conditional expectation of the negative binomial model and found that the former is larger, while in the Poisson model, the two values are equal. The mean of the dependent variable is 1.51, and its variance is 2.77; that is, the variable Y is over-diversified. Therefore, we chose the negative binomial model to conduct the parameter estimation.

Table 2. The mean of five statements of *value perception* ($N = 732$).

Item Number	Content	Mean
D38	Green and low-carbon recycling agricultural production can improve soil fertility and ensure food security.	3.72
D39	Green and low-carbon agricultural production can sustain future generations.	3.73
D42	It is cost-effective to invest in improving agricultural production conditions and green agricultural production.	3.23
D43	If you produce your own green low-carbon and recycling ecological agricultural products, you may be able to sell them at a higher price.	3.43
D44	For food matters that may be risky (such as green recycling ecological agricultural production), I will not try them for the time being.	3.39

3.3.2. Entropy method

There is a variable "value perception" that corresponds to five statements in the questionnaire: (D38) Green and low-carbon recycling agricultural production can improve soil fertility and ensure food security; (D39) Green and low-carbon agricultural production can sustain future generations; (D42) It is cost-effective to invest in improving agricultural production conditions and green agricultural production; (D43) If you produce your own green low-carbon and recycling ecological agricultural products, you may be able to sell them at a higher price; (D44) For food matters that may be risky (such as green recycling ecological agricultural production), I will not try them for the time being. We asked the respondents to what extent they agreed with those statements on an integer scale from 1 (strongly disagree) to 5 (strongly agree). Table 2 shows the mean score of each of five statements.

We needed to integrate the information from these five questions into one variable. The entropy method is a comprehensive evaluation and decision-making method for multiple indicators and multiple objects that excludes expert opinions and other components that could easily be affected by subjective factors. It establishes an evaluation matrix about the evaluation objects and evaluation indexes. Then it determines the weight of each evaluation index (Zhang et al., 2021). It consists of three steps. First, calculate the weight p_{ij} of evaluation object i under the indicator j:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \quad (6)$$

Then, the entropy value E_j of the indicator j is

Table 3. Description of GATs ($N = 732$).

Technologies	Number of farmers that adopted it	Adoption rate (%)
New crop varieties	228	31.1
Less tillage and no tillage	64	8.7
Deep soil loosening	166	22.7
Green manure planting	12	1.6
Water-saving irrigation	51	7.0
Green prevention and control	63	8.6
Straw returning	387	52.9
Livestock and poultry manure use	105	14.3
Recycling agricultural film	12	1.6

Note: A farmer can adopt several technologies.

Table 4. Description of the research variables (N = 732).

Variables	Description	Mean	*S.D.*
Dependent variable			
The number of GATs adopted		1.51	1.66
Channels of knowledge acquisition	1 if a respondent chose the channel, 0 otherwise		
TV		0.30	0.46
Radio		0.07	0.26
Internet		0.11	0.31
Newspaper		0.01	0.09
Government		0.43	0.50
Cooperatives		0.03	0.18
Enterprises		0.01	0.06
Relatives		0.10	0.29
Others		0.04	0.21
Control variables			
Value perception	Calculated by using entropy method	3.45	0.63
Soil fertility	1 (very bad) to 5 (very good)	3.13	1.26
Drainage and irrigation conditions	1 (very bad) to 5 (very good)	3.20	1.31
Total number of household members		4.28	1.78
Total household income	The total household income in 2020	7.83	23.45
Children under 16 years	1 if there are any children under 16 years of age, 0 otherwise	0.46	0.50
Political identity	1 if there are any Communist Party members in the family, 0 otherwise	0.21	0.41
Gender	1 if male, 0 if female	0.58	0.49
Age	The age of the respondent in years	61.12	71.34
Health degree	1 (very unhealthy) to 5 (very healthy)	3.64	1.01
Educational attainment	Years of schooling	6.62	3.94
Farming seniority	Years of farming	36.03	16.59
Terrain type (The reference group is mountain.)	1 if the terrain type is plain, 0 otherwise	0.46	0.50
	1 if the terrain type is hill, 0 otherwise	0.53	0.50

Note: *S.D.* indicates standard deviation.

calculated:

$$E_j = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij}\ln p_{ij},\ j = 1, 2, \ldots, n. \tag{7}$$

Finally, the weight w_j of the indicator j is calculated:

$$w_j = \frac{1 - E_j}{\sum_{j=1}^{n}(1 - E_j)},\ j = 1, 2, \ldots, n. \tag{8}$$

After obtaining the weight of each indicator, the scores of each object i were calculated. Thus, we used this method to obtain the final scores of each farmer's "value perception".

3.4. Selected variables

The dependent variable in our model is the number of GATs adopted by farmers. As it is shown above, it contains at most nine technologies. Table 3 shows the adoption rate for each of the nine GATs. The highest adoption rate was 52.9% (straw returning), the lowest adoption rate was 1.6% (green manure planting and recycling agricultural film), and the adoption rate of six GATs is lower than 20%.

The core explanatory variables are nine channels of knowledge acquisition: TV, radio, the internet (including computers and smartphones), newspapers, the government, cooperatives, enterprises, relatives, and others. By the government, cooperatives, and enterprises, we mean experts or professional staff these institutions send to pass on information about GATs. They mainly disseminate information through field demonstrations or face-to-face training. We asked the respondents what the main channels were for them to acquire knowledge about green, low-carbon and recycling ecological agriculture. If the farmers chose some of them, then each of these channels took the value of 1, and 0 otherwise.

The remaining variables were used as controls. As is shown in the subsection "Entropy Method", we measured value perception by a composite indicator that consisted of respondents' views of the five statements about green agricultural production. Following Mao et al. (2021) and Pham et al. (2021) other control variables selected in our study included individual characteristics, family characteristics, and other characteristics of the respondents (Table 4).

Using a number of controls minimizes the endogeneity problem due to omitted variable (although

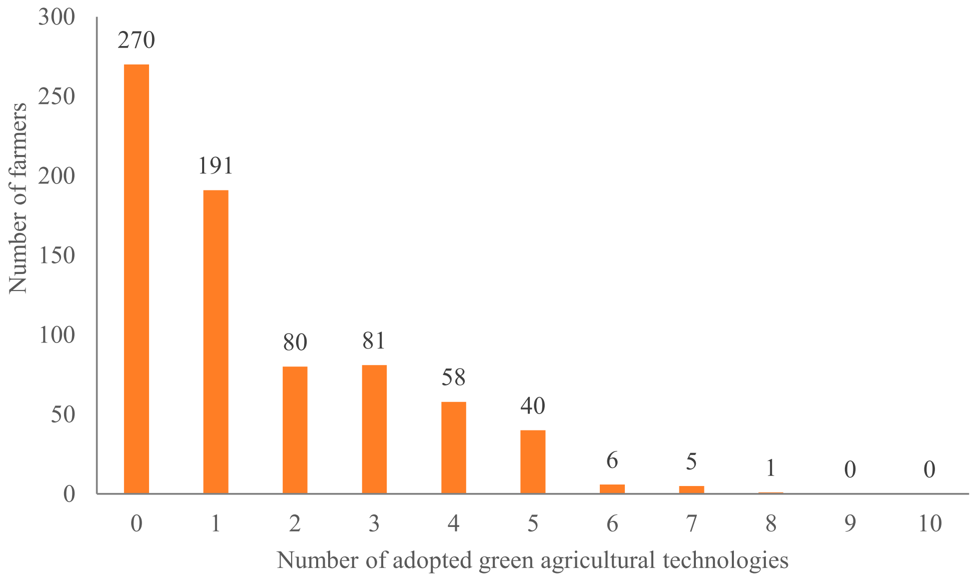

Figure 2. Distribution of farmers' GATs adoption ($N = 732$).

it is practically impossible to exclude its existence). Measurement error could be a source of endogeneity in our analysis, especially if the respondents could not recall exactly which (and how many) channels of knowledge acquisition they had used. Given the character of our dependent variable, the effect of the number of adopted GATs on the channels of knowledge acquisition (i.e. the simultaneity problem) is unlikely. Therefore, we interpret our estimation results as association, not as causality.

4. Results and discussion

4.1. Distribution of GATs adoption and knowledge acquisition

Figure 2 shows the distribution of farmers' GATs adoption. As many as 270 farmers had never adopted GATs before, accounting for 36.8% of the total sample. Nearly two-thirds of the total sample have adopted at least one type of GATs. In addition, Figure 2

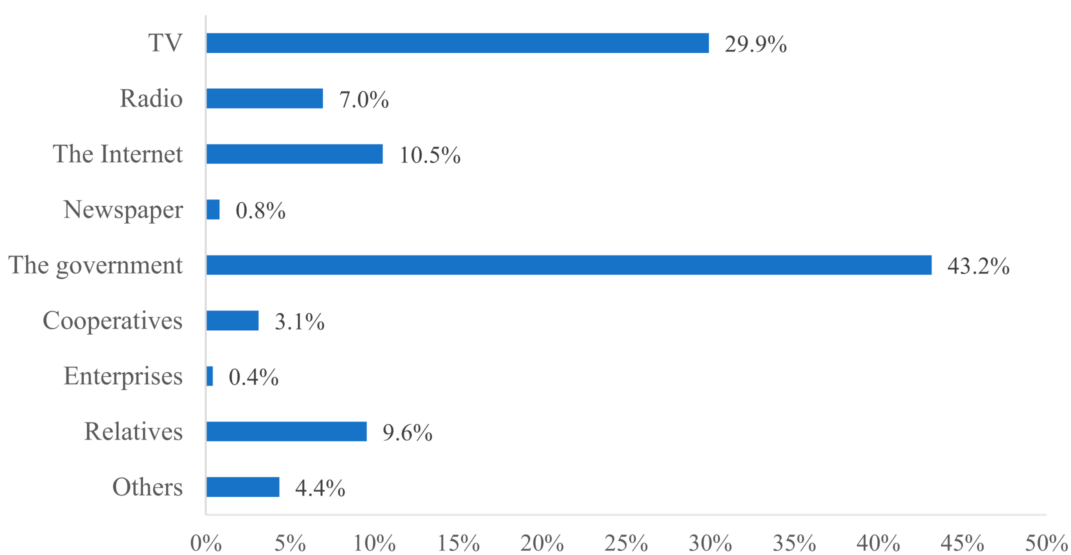

Figure 3. Distribution of knowledge acquisition in different channels ($N = 732$).

shows that the farmers in the sample have adopted at most eight GATs.

As Figure 3 shows, farmers' access to knowledge comes mainly from the government, TV, and the internet, which account for 43.2%, 29.9%, and 10.5% of the sample, respectively. However, a few farmers get the relevant information about green, low-carbon and recycling ecological agriculture through newspapers and enterprises. This is in line with the reality that paper newspapers are currently in decline. The main body of technical information dissemination is the government, indicating that farmers are either more exposed to this information channel or they might trust it more. The government has always played an essential role in Chinese agriculture development (Song et al., 2021). Over the last three decades, the government has invested a lot of resources in developing and deploying agricultural information dissemination systems nationwide. The system normally follows a top-down approach (Zhang et al., 2016). The central department gives instructions, and the local departments will take flexible approaches to help farmers obtain agricultural information. Hence, a lot of useful technical knowledge has been widely disseminated. As a result, enterprises that belong to the private sector have a competitive disadvantage in gaining farmers' trust and delivering information to them.

4.2. Estimation results

The estimation results for the whole sample ($N = 732$) are summarized in Table 5. Model (1) contains only the independent variable and channels of knowledge acquisition, while Model (2) also contains other variables presented in Table 4. As shown in Table 5, the chi-squared test statistics of the two models were significant at the 1% level, which implies the joint significance of those models. As the results of both models are robust, we will concentrate on Model (2).

The results in Table 5 indicate that the radio and the government positively affect farmers' GATs adoption, at the 5% and 1% significance level, respectively. The estimated marginal effect of the radio indicates that if farmers obtain knowledge from the radio, the associated increase in the adoption of GATs is 0.436. However, if farmers get knowledge from the government, the associated increase is higher, namely,

Table 5. Estimation Results of the Negative Binomial Model.

	Model (1) Coefficient	Marginal Effect Coefficient	Model (2) Coefficient	Marginal Effect Coefficient
Channels of knowledge acquisition				
TV	0.106	0.160	0.032	0.048
Radio	0.353***	0.535***	0.288**	0.436**
Internet	0.309**	0.468**	0.173	0.262
Newspaper	0.520	0.788	0.396	0.600
Government	0.684***	1.036***	0.461***	0.698***
Cooperatives	0.221	0.336	0.075	0.113
Enterprises	0.417	0.633	0.057	0.086
Relatives	0.341***	0.517***	0.138	0.210
Others	0.066	0.099	−0.167	−0.253
Value perception			0.217***	0.329***
Soil fertility			0.212***	0.320***
Drainage and irrigation conditions			0.076*	0.116*
Total household population			0.016	0.025
Total household income			0.002	0.003
Children under 16 years old			0.025	0.038
Political identity			−0.263***	−0.398***
Gender			0.153*	0.232*
Age			−0.014**	−0.021**
Health degree			0.211***	0.320***
Educational attainment			0.004	0.006
Farming seniority			0.022***	0.033***
Plain			0.397	0.602
Hills			0.489	0.741
Constant	−0.095	-	−3.084***	-
Log pseudo-likelihood	−1186.432***	-	−1099.525***	-
Pseudo R^2	0.036	-	0.106	-
Observations	732	732	732	732

Notes: ***, **, and * indicate the significance at the 1%, 5%, and 10% levels, respectively.

0.698 GATs. A reason for this may be that the channel of government includes village cadres and grassroots organizations, and they usually organize field demonstrations or face-to-face training by providing paper manuals to promote the use of GATs, which makes it easier for farmers to learn about these technologies. The radio only disseminates information verbally. In addition, farmers in China generally have more trust in the government than the agricultural channels on the radio (Ma et al., 2022), so they are more likely to adopt more GATs through the governmental channels.

However, TV and the internet, which more farmers use than radio in our sample, are insignificant. Many people have left rural China for work to earn more money (Kan & Chen, 2021), resulting in the remaining farmers being generally older. Combined with their lower education level, this makes them less receptive to new things. Therefore, these farmers do not actively use the internet and obtain information through TV. Furthermore, when farmers get information from TV or the internet, there is much more other information available that is not related to green agricultural development (Uzuegbu, 2016).

The reason for the insignificant influence of newspapers can be explained by the gradual decline in traditional paper media in China (Liu et al., 2017). As a result, very few farmers (1% in Table 4) use newspaper as a channel of knowledge acquisition. This leads to an insignificant association between newspaper and the adoption of GATs. We also found an insignificant influence of enterprises, cooperatives, and relatives (although this channel has been used be nearly 10% of the farmers in our sample). Compared with the government, which means authority for farmers, knowledge exchange between relatives is informal (Xu et al., 2021). It would not leave a lasting impression in farmers' minds, while the government tends to use personal demonstrations to transfer green agriculture-related knowledge, which represents an easier way for imitation to farmers and has a very direct link to their degree of green technologies adoption. This might explain why knowledge gained from relatives does not significantly affect farmers' adoption degree of GATs.

5. Conclusions and policy implications

In this paper, we analyzed survey data from 732 farmers in Hubei, China, to gain a preliminary understanding of the channels of knowledge acquisition and adoption of GATs in this province. We found that a large number of farmers adopted some of the GATs, and some even adopted several in combination (e.g. 11% of the farmers in the sample adopted three GATs).

Television and government channels were the most commonly reported sources of information on GATs for farmers. However, television is not a decisive factor in determining the number of GATs adopted. From this perspective, the ratio and government channels are the most important sources of knowledge acquisition.

Although our results are based on a sample from a specific province in China, they may indicate the difference between private and public channels of knowledge acquisition, since TV, Internet, cooperatives, enterprises, or relatives were not significant factors associated with the number of adopted GATs, unlike radio and government channels. A second conclusion is that among the significant factors, the one that uses direct communication with farmers (i.e. government channels) and allows practical demonstration of the benefits of GATs is associated with a higher rate of GAT adoption than radio, which can only transmit passive information.

A practical policy recommendation that follows from our findings is that the government should first broadcast GATs information campaigns over the radio to reach as many farmers as possible, and then, in the second phase, complement them with outreach professionals who would visit farmers, demonstrate the new technologies, and answer any questions farmers may have.

It should be noted that although the Internet was not a significant factor associated with the number of GATs adopted in our sample, it is possible that this channel will become a significant factor in the future, as digitalization progresses and education levels improve in rural China.

Our conclusions are subject to several limitations, at least three of which are worth mentioning. First, the sample size and coverage of villages (although random) make the results and conclusions context-specific and therefore difficult to generalize. This was underscored by comparing the descriptive statistics of our sample with those of Hubei province. Second, the nonexperimental nature of our data makes it difficult to draw causal inferences. Third, our results are static (i.e. based on cross-sectional data). From a policy perspective, it would be interesting to see how long farmers stick to the GATs they initially adopted.

Although this paper lists possible reasons for the heterogeneity in the different knowledge acquisition channels, these reasons should be further explored in the future. Furthermore, although it was not the focus of this paper, we found a positive correlation between value perceptions and the number of GATs adopted by farmers. Considering the literature on farmers' perceptions and behaviour change, investigating the effect of value perception on the relationship between knowledge acquisition channels and farmers' adoption of GATs may be another interesting topic.

Notes

1. Conventional farming in developing countries exhibits largescale intensified agriculture, which causes serious local, regional, and global environmental consequences (Matson, Parton, Power, & Swift, 1997).
2. The Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) program, which is supported by the United States Agency.
3. Parastatals are public organizations that are separate from the government, but whose activities serve the state.
4. The magnitude of the effect of different mass media (e.g., TV and radio) on the adoption of agricultural technology differs (e.g., Awuni, Azumah, & Donkoh, 2018).
5. According to China Statistical Yearbook (2021), which is a collection of some of China's statistical indicators in 2020.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was funded by the Key Project of National Social Science Fund (No. 20AZD091) and the scholarship granted by the China Scholarship Council (CSC). Dušan Drabik acknowledges financial support from the Slovak Research and Development Agency (Contract No. APVV-21-0174) and from Operational Programme – Integrated Infrastructure (Project No. Drive4SIFood 313011V336.

Data availability

The underlying data for this analysis are available from the authors upon request.

References

Anderson, J. R., & Feder, G. (2007). Agricultural extension. *Handbook of Agricultural Economics*, *3*, 2343–2378. https://doi.org/10.1016/S1574-0072(06)03044-1

Antle, J. M., & Diagana, B. (2003). Creating incentives for the adoption of sustainable agricultural practices in developing countries: The role of soil carbon sequestration. *American Journal of Agricultural Economics*, *85*(5), 1178–1184. https://doi.org/10.1111/j.0092-5853.2003.00526.x

Awuni, J. A., Azumah, S. B., & Donkoh, S. A. (2018). Drivers of adoption intensity of improved agricultural technologies among rice farmers: Evidence from northern Ghana. *Review of Agricultural and Applied Economics*, *21*(2), 48–57. https://doi.org/10.15414/raae.2018.21.02.48-57

Azumah, S. B., Donkoh, S. A., & Awuni, J. A. (2018). The perceived effectiveness of agricultural technology transfer methods: Evidence from rice farmers in Northern Ghana. *Cogent Food & Agriculture*, *4*(1), 1503798. https://doi.org/10.1080/23311932.2018.1503798

Barbosa, G., Gadelha, F., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., Wohlleb, G., & Halden, R. (2015). Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. *International Journal of Environmental Research and Public Health*, *12*(6), 6879–6891. https://doi.org/10.3390/ijerph120606879

Bukchin, S., & Kerret, D. (2018). Food for hope: The role of personal resources in farmers' adoption of green technology. *Sustainability*, *10*(5), 1615. https://doi.org/10.3390/su10051615

Chen, M., Zhang, L., Teng, F., Dai, J., Li, Z., Wang, Z., & Li, Y. (2020). Climate technology transfer in BRI era: Needs, priorities, and barriers from receivers' perspective. *Ecosystem Health and Sustainability*, *6*(1), 1780948. https://doi.org/10.1080/20964129.2020.1780948

Chinese National Bureau of Statistics. (2021). http://www.stats.gov.cn/.a.

Coleman, J. S. (1964). *Introduction to mathematical sociology*. Free Press.

Coromaldi, M., Pallante, G., & Savastano, S. (2015). Adoption of modern varieties, farmers' welfare and crop biodiversity: Evidence from Uganda. *Ecological Economics*, *119*, 346–358. https://doi.org/10.1016/j.ecolecon.2015.09.004

Dong, Q., Yang, Y., Yu, K., & Feng, H. (2018). Effects of straw mulching and plastic film mulching on improving soil organic carbon and nitrogen fractions, crop yield and water use efficiency in the Loess Plateau, China. *Agricultural Water Management*, *201*, 133–143. https://doi.org/10.1016/j.agwat.2018.01.021

FAO. (2017). *The future of food and agriculture: Trends and challenges* (pp. 3–150). Food and Agriculture Organization of the United Nations.

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, *33*(2), 255–298. https://doi.org/10.1086/451461

Gao, Y., Zhao, D., Yu, L., & Yang, H. (2020). Influence of a new agricultural technology extension mode on farmers' technology adoption behavior in China. *Journal of Rural Studies*, *76*, 173–183. https://doi.org/10.1016/j.jrurstud.2020.04.016

Goto, M., Fujita, K., & Sueyoshi, T. (2020). Marginal effect of R&D investment and impact of market reforms—An empirical analysis of Japanese electric power companies. *Energies*, *13* (*13*), 3354. http://doi.org/10.3390/en13133354

Hansen, B., Alrøe, H. F., & Kristensen, E. S. (2001). Approaches to assess the environmental impact of organic farming with particular regard to Denmark. *Agriculture, Ecosystems & Environment*, *83*(1-2), 11–26. https://doi.org/10.1016/S0167-8809(00)00257-7

He, P., Zhang, J., & Li, W. (2021). The role of agricultural green production technologies in improving low-carbon efficiency in China: Necessary but not effective. *Journal of Environmental Management*, *293*, 112837. https://doi.org/10.1016/j.jenvman.2021.112837

Huang, J., Hu, R., Cao, J., & Rozelle, S. (2008). Training programs and in-the-field guidance to reduce China's overuse of fertilizer without hurting profitability. *Journal of Soil and Water Conservation*, *63*(5), 165A–167A. https://doi.org/10.2489/jswc.63.5.165A

Huisingh, D., Zhang, Z., Moore, J. C., Qiao, Q., & Li, Q. (2015). Recent advances in carbon emissions reduction: Policies, technologies, monitoring, assessment and modeling. *Journal of Cleaner Production*, *103*, 1–12. https://doi.org/10.1016/j.jclepro.2015.04.098

Kabunga, N. S., Dubois, T., & Qaim, M. (2012). Heterogeneous information exposure and technology adoption: The case of tissue culture bananas in Kenya. *Agricultural Economics*, *43*(5), 473–486. https://doi.org/10.1111/j.1574-0862.2012.00597.x

Kan, K., & Chen, X. (2021). Tilling another's land: Migrant farming under rural industrialization and urbanization in China. *Journal of Agrarian Change*, https://doi.org/10.1111/joac.12464

Li, F., Ren, J., Wimmer, S., Yin, C., Li, Z., & Xu, C. (2020). Incentive mechanism for promoting farmers to plant green manure in China. *Journal of Cleaner Production*, *267*, 122197. https://doi.org/10.1016/j.jclepro.2020.122197

Li, J., Zhang, Y., & Cui, B. (2018). 'Internet +' is used to promote the upgrading of agricultural technology extension mode. *Primary Agricultural Technology Extension*, *6*, 7–8. in Chinese.

Li, M., Wang, J., Zhao, P., Chen, K., & Wu, L. (2020). Factors affecting the willingness of agricultural green production from the perspective of farmers' perceptions. *Science of The Total Environment*, *738*, 140289. https://doi.org/10.1016/j.scitotenv.2020.140289

Liu, X. (2023). Sustainable intensification: A historical perspective on China's farming system. *Farming System*, *1*(1), 100001. https://doi.org/10.1016/j.farsys.2023.100001

Liu, Y., Chen, W., & Li, J. (2017). Transformation and development of traditional media in new media environment. In Xie Y. G. (Ed.), *New media and China's social development* (pp. 25–46). Springer.

Liu, Y., Ruiz-Menjivar, J., Zhang, L., Zhang, J., & Swisher, M. E. (2019). Technical training and rice farmers' adoption of low-carbon management practices: The case of soil testing and formulated fertilization technologies in Hubei, China. *Journal of Cleaner Production*, *226*, 454–462. https://doi.org/10.1016/j.jclepro.2019.04.026

Ma, Z., Guo, S., Deng, X., & Xu, D. (2022). Place attachment, community trust, and farmer's community participation: Evidence from the hardest-hit areas of Sichuan, China. *International Journal of Disaster Risk Reduction*, *73*, 102892. https://doi.org/10.1016/j.ijdrr.2022.102892

Mao, H., Zhou, L., Ying, R., & Pan, D. (2021). Time preferences and green agricultural technology adoption: Field evidence from rice farmers in China. *Land Use Policy*, *109*, 105627. https://doi.org/10.1016/j.landusepol.2021.105627

Mapiye, O., Makombe, G., Molotsi, A., Dzama, K., & Mapiye, C. (2021). Information and communication technologies (ICTs): The potential for enhancing the dissemination of agricultural information and services to smallholder farmers in sub-Saharan Africa. *Information Development*, *39*(3), 638–658. https://doi.org/10.1177/02666669211064847

Matson, P. A., Parton, W. J., Power, A. G., & Swift, M. J. (1997). Agricultural intensification and ecosystem properties. *Science*, *277*(5325), 504–509. https://doi.org/10.1126/science.277.5325.504

Mwombe, S. O. L., Mugivane, F. I., Adolwa, I. S., & Nderitu, J. H. (2014). Evaluation of information and communication technology utilization by small holder banana farmers in Gatanga District, Kenya. *The Journal of Agricultural Education and Extension*, *20*(2), 247–261. https://doi.org/10.1080/1389224X.2013.788454

Ndiwalana, A., Scott, N., Batchelor, S., & Sumner, A. (2010). Information needs and communication patterns of rural Uganda: Implications for mobile applications. M4D 2010 137.

Nikam, V., Kumar, S., Kingsly, I. M., & Roy, M. (2020). Farmers mobile use pattern, information sources and perception about mobile app for grapes. *Indian Journal of Extension Education*, *56*, 77–83.

Nin-Pratt, A., & McBride, L. (2014). Agricultural intensification in Ghana: Evaluating the optimist's case for a green revolution. *Food Policy*, *48*, 153–167. https://doi.org/10.1016/j.foodpol.2014.05.004

Ochieng, J., Afari-Sefa, V., Muthoni, F., Kansiime, M., Hoeschle-Zeledon, I., Bekunda, M., & Thomas, D. (2021). Adoption of sustainable agricultural technologies for vegetable production in rural Tanzania: Trade-offs, complementarities and diffusion. *International Journal of Agricultural Sustainability*, 478–496. https://doi.org/10.1080/14735903.2021.1943235

Olumese, M. I., Imarhiagbe, P., & Imafidon, S. (2018). Relationship between information communication technology and adoption of improved cassava technologies in Edo State, Nigeria. *Journal of Agricultural Extension*, *22*(1), 277–285. https://doi.org/10.4314/jae.v22i1.27S

Pham, H.-G., Chuah, S.-H., & Feeny, S. (2021). Factors affecting the adoption of sustainable agricultural practices: Findings from panel data for Vietnam. *Ecological Economics*, *184*, 107000. https://doi.org/10.1016/j.ecolecon.2021.107000

Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). *Diffusion of innovations*. Routledge.

Rupani, P., Maleki Delarestaghi, R., Asadi, H., Rezania, S., Park, J., Abbaspour, M., & Shao, W. (2019). Current scenario of the Tehran municipal solid waste handling rules towards green technology. *International Journal of Environmental Research and Public Health*, *16*(6), 979. https://doi.org/10.3390/ijerph16060979

Segura, H. R., Barrera, J. F., Morales, H., & Nazar, A. (2004). Farmers' perceptions, knowledge, and management of coffee pests and diseases and their natural enemies in Chiapas, Mexico. *Journal of Economic Entomology*, *97*(5), 1491–1499. https://doi.org/10.1603/0022-0493-97.5.1491

Song, X., Wang, X., Li, X., Zhang, W., & Scheffran, J. (2021). Policy-oriented versus market-induced: Factors influencing crop diversity across China. *Ecological Economics*, *190*, 107184. https://doi.org/10.1016/j.ecolecon.2021.107184

Spielman, D., Lecoutere, E., Makhija, S., & van Campenhout, B. (2021). Information and communications technology (ICT) and agricultural extension in developing countries. *Annual Review of Resource Economics*, *13*(1), 177–201. https://doi.org/10.1146/annurev-resource-101520-080657

Tambo, J. A., Aliamo, C., Davis, T., Mugambi, I., Romney, D., Onyango, D. O., Kansiime, M., Alokit, C., & Byantwale, S. T. (2019). The impact of ICT-enabled extension campaign on farmers' knowledge and management of fall armyworm in Uganda. *PLoS One*, *14*(8), e0220844. https://doi.org/10.1371/journal.pone.0220844

Tey, Y. S., Li, E., Bruwer, J., Abdullah, A. M., Brindal, M., Radam, A., Ismail, M. M., & Darham, S. (2014). The relative importance of factors influencing the adoption of sustainable agricultural practices: A factor approach for Malaysian vegetable farmers. *Sustainability Science*, *9*(1), 17–29. https://doi.org/10.1007/s11625-013-0219-3

Uzuegbu, C. P. (2016). Effective information service delivery to rural dwellers in Sub-Saharan Africa. *IFLA Journal*, *42*(1), 49–58. https://doi.org/10.1177/0340035215608860

Vasudevan, S. (2022). Radio and technology adoption during India's green revolution: Evidence from a natural experiment. *World Development*, https://doi.org/10.2139/ssrn.4059448

Voss, R. C., Jansen, T., Mané, B., & Shennan, C. (2021). Encouraging technology adoption using ICTs and farm trials in Senegal: Lessons for gender equity and scaled impact. *World Development*, *146*, 105620. https://doi.org/10.1016/j.worlddev.2021.105620

Wainaina, P., Tongruksawattana, S., & Qaim, M. (2016). Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya. *Agricultural Economics*, *47*(3), 351–362. https://doi.org/10.1111/agec.12235

Wang, W., Wang, J., Liu, K., & Wu, Y. J. (2020). Overcoming barriers to agriculture green technology diffusion through stakeholders in China: A social network analysis. *International Journal of Environmental Research and Public Health*, *17*(19), 6976. https://doi.org/10.3390/ijerph17196976

Xie, S., Feng, H., Yang, F., Zhao, Z., Hu, X., Wei, C., Liang, T., Li, H., & Geng, Y. (2019). Does dual reduction in chemical fertilizer and pesticides improve nutrient loss and tea yield and quality? A pilot study in a green tea garden in Shaoxing, Zhejiang Province, China. *Environmental Science and Pollution Research*, *26*(3), 2464–2476. https://doi.org/10.1007/s11356-018-3732-1

Xu, C., Li, L., & Cheng, B. (2021). The impact of institutions on forestland transfer rents: The case of Zhejiang province in China. *Forest Policy and Economics*, *123*, 102354. https://doi.org/10.1016/j.forpol.2020.102354

Yin, R., Luo, X., Li, R., & Huang, Y. (2018). Under the background of informatization, why do farmers favor agricultural technicians to carry out agricultural technology extension in the field? *Research of Agricultural Modernization*, *39*, 576–583. DOI:10.13872/j.1000-0275.2018.0037. In Chinese.

Zeng, Y., Tian, Y., He, K., & Zhang, J. (2020). Environmental conscience, external incentives and social norms in rice farmers' adoption of pro-environmental agricultural practices in rural Hubei province, China. *Environmental Technology*, *41*(19), 2518–2532. https://doi.org/10.1080/09593330.2019.1574907

Zhang, L. X., Bai, Y. L., Sun, M. X., Xu, X. B., & He, J. L. (2021). Views on agricultural green production from the perspective of system science. *Issues in Agricultural Economy*, *10*, 42–50. https://doi.org/10.13246/j.cnki.iae.2021.10.004. in Chinese.

Zhang, M., Cui, W.-K., Zhang, Y.-J., & Xu, Y.-H. (2021). Research on world food production efficiency and environmental sustainability based on entropy-DEA model. *Complexity*, 1–11. https://doi.org/10.1155/2021/8730264

Zhang, Y., Wang, L., & Duan, Y. (2016). Agricultural information dissemination using ICTs: A review and analysis of information dissemination models in China. *Information Processing in Agriculture*, *3*(1), 17–29. doi:10.1016/j.inpa.2015.11.002

Zhao, Q., Pan, Y., & Xia, X. (2021). Internet can do help in the reduction of pesticide use by farmers: Evidence from rural China. *Environmental Science and Pollution Research*, *28*(2), 2063–2073. https://doi.org/10.1007/s11356-020-10576-8