Journal of Integrative Agriculture 2022, 21(6): 1799–1811

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RESEARCH ARTICLE

ICT-based agricultural advisory services and nitrogen management practices: A case study of wheat production in China

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Abstract

Excessive use of nitrogen fertilizer in China and its adverse effects on agricultural production have been a national and global concern. In addition to massive public initiatives to promote sustainable farm practices, grass-rooted innovations are emerging in the niche, many of which take the forms of information and communication technologies (ICT) and digital services. This study examines the effects of ICT-based extension services provided by an entrepreneurial startup on adopting sustainable farming practices. We found no significant reduction in N-fertilizer use for wheat production. But the ICT-based services promoted farmers to adapt N-fertilizer use towards site-specific management. The business model of the entrepreneurial venture faces great challenges in becoming participatory and financially sustainable.

Keywords: venture capital, innovations, precision farming, private–public partnerships, nitrogen management

1. Introduction

Although the use of fertilizers has played an important role in achieving China's food security, fertilizers have been applied at excessive rates and have led to serious environmental problems. Between 1980 and 2010, fertilizer use in China's grain production increased by 438% while yields only increased by 170%, indicating the declining efficiency of fertilizer use (Cui *et al.* 2008; Powlson *et al.* 2014; Huang *et al.* 2015). Numerous studies revealed unprecedented environmental problems and significant greenhouse gas (GHG) emissions associated with excessive use of nitrogen fertilizer (N-fertilizer) (Kahrl *et al.* 2010; Zhang *et al.* 2013; Wu *et al.* 2021). For example, soil acidification has become a serious problem in recent decades, to which the acidification stemming from the high inputs of ammonium-based N fertilizer has contributed about 60% (Guo *et al.* 2010). The incidence of algal blooms in surface water has increased several-fold since the 1990s, and N-fertilizer use is responsible for 25–80% NH_3 volatilization caused by agriculture in China (Powlson *et al.* 2014). In 2010, total GHG emissions associated with N-fertilizer (both manufacture and use) represented 7% of total emissions from China (Zhang *et al.* 2013).

Received 18 October, 2021 Accepted 17 February, 2022
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doi: 10.1016/S2095-3119(21)63859-5

Major efforts have been made by scientists to optimize nitrogen management through information and knowledge interventions. Farmers in developing countries rely mostly on their own experience, which is passed on by word-of-mouth *via* local social networks (Duveskog *et al.* 2003). For example, a substantial percentage of Chinese farmers wrongly believe that using more fertilizer unconditionally increases yield (Jia *et al.* 2015). A study by Cui *et al.* (2005) found that scientific nitrogen management based on soil analyses and improved synchronization between crop nitrogen demand and nitrogen supply can reduce 196 kg N ha^{-1} without reducing wheat yields, saving 60% of N-fertilizer in China. Jia *et al.* (2013) examined the effects of knowledge training on low-carbon farm practices and found that the in-season N-fertilizer use could be reduced by 20% without affecting maize yields in China. Huang *et al.* (2015) designed an experimental framework and compared the long-term effects of site-specific farm advisory services and traditional training approaches in China. Some studies discovered that, in addition to information and knowledge, demographic and contextual factors (e.g., education, risk aversion, and access to credit) also determined farmers' behaviors and decision-making with respect to sustainable farm practices (Sunding and Zilberman 2001; Silvia *et al.* 2021). Their studies revealed major limitations of traditional knowledge training without farmers' participation. By engaging farmers in field experiments and crop diagnoses, excessive N-fertilizer use can be reduced without adversely affecting crop yield, and the effects of learning continue in the long term.

The societal need to transform agriculture towards sustainability has engaged entrepreneurial innovations and digital technologies in China. The development of digitalization in rural China offers entrepreneurial finance and startups a broad opportunity to provide agro-technical services with the aid of information and communication technologies (ICTs). The Chinese government undertook promising actions to expedite informatization in the mid-1970s, but most public investments were spent on developing capacities in urban areas. Since the 1990s, vast investments have been made by the public and private sectors to increase the coverage of informatization infrastructure in rural China, including mobile phones, fixed line telephones, radio, television, and internet (Qiang *et al*. 2009). According to NBSC (2016) and CNNIC (2016), 60% and more than 31% of the rural population owns a mobile phone and has access to the Internet, respectively. Between 2010 and 2016, a total of 262 startups obtained funding thanks to entrepreneurial finance, such as venture capital (VC) and private equity. Among them, 38 focused on agro-technical services, and half were established in 2016, accounting for 27% of VC cases linked with food and agriculture in that year (Jia 2017).

While entrepreneurial innovations in digitalization have been a major source of transforming businesses (Van Campenhout *et al.* 2021), their presence and effects on sustainable farm practices are far from clear. Early research studied ICTs as a medium of dissemination of information and knowledge in agricultural development (Rao 2008; Aker 2011). Some anecdote studies concluded that the role of ICTs in different forms (radio, short message service (SMS), mobile phones, and the Internet) in agriculture is variable and may even be overstated (Jensen 2007). Most of these studies were conducted in development or social-purpose programs. A rigorous examination of emerging entrepreneurial startups and their impacts on sustainable farm practices is rare, especially in the context of the venture capital industry's emerging interest in China's agricultural transformation.

The overall goal of this study is to explore the effects of ICT-based advisory services on nitrogen management in wheat production in the North China Plain. In addition, the study explores the new forms of public–private partnerships and investigates the organizational characteristics of delivering sustainable farm services by entrepreneurial startups. The following section presents the research design, data collection method, and empirical models. Section 3 describes nitrogen-optimization technologies in the study, the ICT protocol used by the startup, and the estimation results. Sections 4 and 5 present the discussion and conclusions, respectively.

The study has particular value for the global debates about digital transformation and innovations in sustainable agriculture in developing countries. As an emerging concept and approach aimed at shifting farming systems towards resilience and adaptability, digital transformation seeks to promote synergies by "taking these objectives into consideration to inform decisions from the local to the global scales and over short and long timer horizon, to derive locally-acceptable solutions" (FAO 2021). Given the limitations of the public extension system and the top-down approaches, entrepreneurial innovations could be an alternative to public institutions. If proven successful, the new private model could shift both farming and extension systems toward more flexible and adaptable management. Experimental studies have found that ICT-based agricultural advisory services significantly affected farmers' fertilizer-related decisions (Kaila and Tarp 2019; Cole and Fernando 2021). If sustainable approaches to agroecology do succeed in reducing nitrogen fertilizer use, the site-specific ICTs will become a technological solution that helps promote China's food security sustainably.

2. Materials and methods

2.1. Context and research design

The research was conducted as part of a large-scale national research program into excessive fertilizer use in China. In 2015, the Ministry of Agriculture and Rural Affairs (formerly known as the Ministry of Agriculture) announced the "Zero-Growth Action Plan for Chemical Fertilizers and Pesticides" (hereafter referred to as Action Plan). The Action Plan was a national call to restrict the annual increase in the use of chemical fertilizers and pesticides to less than 1% between 2015 and 2019 and to achieve zero increase by 2020 for major agricultural crops, compared to the annual 3.9% increase in nitrogen use between 2000 and 2013 through China. In 2016, to ensure that scientific researches match national requirements, the Ministry of Science and Technology started a large-scale research program called "Researching and Developing Technologies for Reducing Chemical Fertilizer and Pesticide and Strengthening Efficiency" (hereafter, the National Research Program). Upon the proposal, the Ministry of Finance approved funding totaling US$ 363.6 million for the National Research Program for the period 2016–2018. The National Research Program comprises 49 projects from multiple perspectives, one of which focuses on the theme of "Informatization and Sustainable Management on Fertilizer" (hereafter, the Project).

The National Research Program highlighted innovations by engaging multiple stakeholders which involve scientists, public extension officers, and private sectors. The interdisciplinary group of scientists integrated expertise in agronomy, soil and environmental sciences from different institutions. To explore a new form of public–private partnership, the Project identified one entrepreneurial startup for partnering with private sectors. Receiving research funding, the scientists provided academic support to the entrepreneurial firm which developed information and communication facilities and delivered agroecological advisory services to farmers. Rather than charging farmers service fees, the startup's revenues came mainly from selling agrochemicals to farmers. The startup hired local extension officers (as part-time consultants) in county agricultural bureaus for rapid outreach and local knowledge. Fig. 1 illustrates the schematic flow chart of the organization.

The present study was conducted as an independent evaluation of the effectiveness and organizational capacity of ICT-based farmer services provided by the entrepreneurial venture. After several months of communication among the multiple stakeholders of the Project, the scientists and the startup agreed to share information and data to make the research a pilot and case study. A light-touch approach was used as a precondition for implementing the evaluation throughout the lifetime of the project; researchers undertook independent observations and limited their interventions

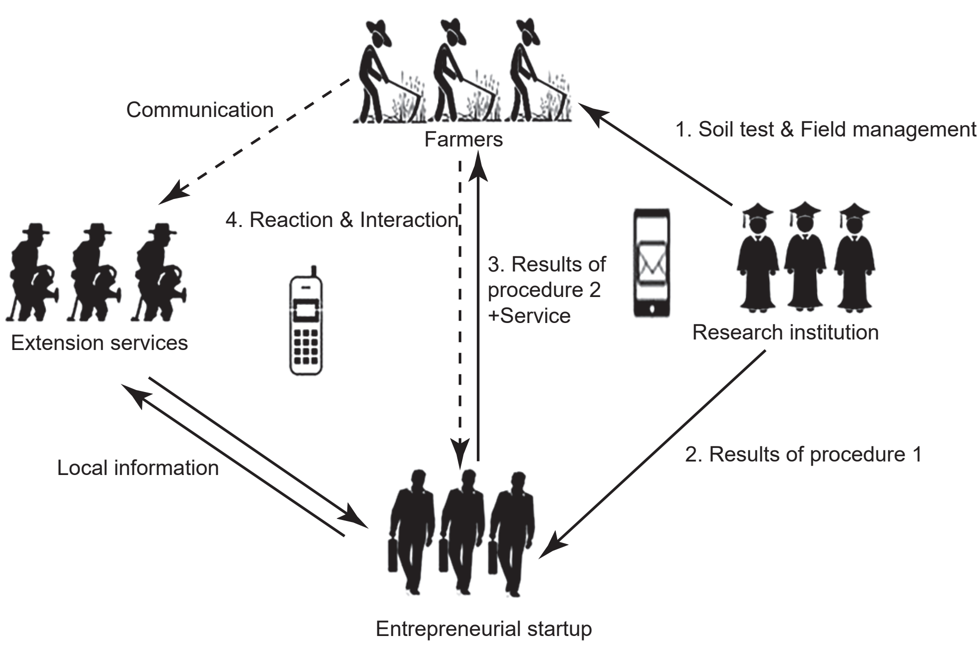

Fig. 1 A schematic flow chart explaining the business model of the startup. Dashed lines indicate activities with farmers' reaction; solid lines indicate activities without farmers' reaction.

in company's business to the minimum, which ensured a distance between the evaluator and the Project and avoided incurring additional costs and resources to the Project.

The case study was conducted in Shandong Province, where the entrepreneurial startup provided agroecological services. The startup obtained seed capital from a venture cash capital investor in 2015. The founding partners of the startup had mixed career backgrounds in fertilizer manufacture and information services such as social media and informatics. The partnerships between the Project and the startup combined the complementary capacities and resources of multiple stakeholders. Farmer services were provided in Binzhou, a northern prefecture in Shandong Provice, which has an annual rainfall of 567.7 mm. The local annual mean temperature and sunshine hours reach 12.3°C and 2 704.2 hours, respectively. Meanwhile, winter wheat and summer maize are planted in rotation in the case study area. Winter wheat is routinely planted at the end of September (after the maize harvest) and harvested in the following June.

Previous research found excessive nitrogen fertilizer use and lack of appropriate knowledge about sustainable fertilizer use in the region. For example, based on field experiments lasting several years, soil scientists argued that 128 kg N ha^{-1} could be saved in the winter wheat cropping season (Norse *et al.* 2012). Similar evidence has also been provided by other researchers, supporting a significant reduction in fertilizer use, or alternatively, soil acidification and surface water algal blooms (Vitousek *et al.* 2009). Despite robust scientific evidence and active policy advocacy, inappropriate nitrogen management, which suggests that more fertilizer leads to more yield, persisted and was deeply rooted in farmers' perceptions; the public extension system was dysfunctional due to low accountability (Jia *et al.* 2015). For example, only 28% of farmers were able to read the nutrient labeling on fertilizer packaging, and 44% of farmers wrongly believed "the more fertilizer, the better" in Shandong Province (Jia *et al.* 2015).

In this study, farmers were advised to reduce overall N-fertilizer use and to optimize nitrogen use at variable rates according to the crop growth stage and site-specific variability. A limit of 180–220 kg ha^{-1} was advised for total N-fertilizer use in the region. The rate 180–220 kg N ha^{-1} application was established based on the wheat requirements for achieving maximum economic yield and the soil nutrient uptake. According to the handbook of fertilization of major cash crops in China, only 2.3 kg N was needed to produce 100 kg wheat grain yield (Zhang *et al.* 2009). In the North China Plain, yield of wheat in the wheat–maize doubled crop rotation were 7–10 t ha^{-1}, with an annual optimum N application of 180–220 kg N ha^{-1}. This variable rate of N-fertilizer use and precision farming should avoid any surplus N reaching the environment and improve both yield and nitrogen use efficiency (Matson *et al.* 1998; Tilman *et al.* 2002).

In addition, the startup advised farmers to adjust N-fertilizer application at different stages for a better match between crop nitrogen demand and the nitrogen supplied by fertilizer and by the soil nutrient. In principle, the farmers were advised to apply N-fertilizer at a ratio of 1:1, namely 100 kg N ha^{-1} at the basal stage of the growing season, and another 100 kg N ha^{-1} as a top dressing. The N management strategy at the basal stage was based on soil test. Prior to the 2016–2017 cropping season (i.e., shortly after the maize harvest in September), 86 sample soil plots at 0–20 cm soil layer were randomly taken from 45 farmers before planting and after the harvest. The soil samples were used to measure soil nutrients such as total N content, organic matter content, Olsen-P, NH_4OAc-K, and pH level. Excessive use of N-fertilizer in the early stage is neither economically justified nor productive because young crops have limited capacity to uptake N, which is attributed to the lack of an extensive root system in the early growth stage (Sinclair and Rufty 2012). The latter 100 N kg ha^{-1} strategy applies N fertilizer once or twice and the optimum N rates at the top dressing stage is based on the actual tiller number and crop population, which was affected by the growing period climate and soil nutrient. Specifically, three randomly selected 0.5 m wheat of single row at each sample plot were counted by scientists to determine the total tiller number. The plot with the greatest tiller number (900 m^{-2}) requires N fertilizer to be applied twice: first during the reviving stage (52.5 kg N ha^{-1}) and again during the jointing stage (60 kg N ha^{-1}). An average of 112.5 kg N ha^{-1} was used at the erecting stage in total tiller number with a range from 900 to 1 200 m^{-2}. Across the plots with the total tiller number ranging from 1 200 to 1 500 m^{-2}, an average of 112.5 kg N ha^{-1} was applied at the jointing stage (Chen *et al.* 2016).

The SMS-based messaging tools were used for communication. Scientists analyzed all the data and rapidly transferred the results to the startup whose staff further calibrated the parameters according to the feedback from the local extension agents. Finally, after combining site-specific information (climate, soil analyses, seed variety, crop rotation, etc.), the startup drew up a set of guidelines for sustainable practices and sent them to the contacted farmers. Both SMS and messaging applications installed on smartphones were planned, but the company ultimately used SMS-based messaging to communicate with all the farmers.[1] The benefiting farmers are hereafter referred to as 'treated' farmers. Throughout the wheat growing season in 2016–2017, the startup sent a total of eight messages to each of the treated farmers with detailed advice on how to conduct sustainable farm management. Together with the advice, the startup also sent the results of the diagnosis — either site-specific or community-based — to the farmers, including the results of soil analyses, crop population, leaf analysis, and weather. A local extension agent was identified in the messages in case farmers had additional inquiries or requests. The details of technical regulations and in-field guidance are summarized in Table 1.

2.2. Survey and data collection

The sampling strategy aimed at a trade-off between a 'light-touch' intervention that would capture the natural course of the pilot project and statistical legitimacy. Based on the agreement between the research team and the startup, in this case study, researchers presented themselves as independent observers (but not advisors). The startup refused the researchers' proposal of randomly assigning the treatment (i.e., the provision of ICT-based advisory services) as being used in several other studies with random control trials (Guo *et al.* 2010) or framed interventions (Huang *et al.* 2015). The startup insisted on consulting local extension agents to identify "best suited" farms whose size is relatively large in the selected village and who will be potential customers of the startup in the future, meaning the 'treatment' suffered from potential selection bias. However, thanks to the agreement, the startup provided the research team with a complete list of the farmers they were advising (or about to advise); these farmers were identified as "treated" in the analysis. On average, the startup provided advisory services for two treated farmers in each village. Within each farmer, two plots were randomly selected. In total, there were 45 treated farmers in 25 village communities that were attached to nine townships in four counties, in Binzhou City, Shandong Province. To have a control group in the same village and neighboring communities, this study randomly selected eight farmers per village who used the same wheat–maize crop rotation system and received no direct farming services from the startup. Therefore, the research design was framed under a with–without analysis, although the sample selection bias remained a concern.

To address potential estimation bias due to the non-random sampling and to control for time-invariant factors, this study conducted two-round surveys and designed a before–after analytical framework based on the same respondents. The baseline survey was conducted in mid-November 2016, through a face-to-face questionnaire-based interview. The main aim of the baseline survey was to investigate farm management during the 2015–2016 wheat growing season (i.e., before the startup pilot program began). In addition to the general information, all surveyed farmers were asked about details concerning inputs (especially fertilizer use) and yield from their own randomly selected two plots. One year later, at the end of the same cropping season, the research team returned to the same farms and conducted a follow-up survey. While the majority of survey questions were identical to those used in the baseline survey, the follow-up survey asked the farmers in the treated group, who had received short messages and site-specific agroecological services, questions concerning their awareness, perception, and feedback linked with the services. For example, if a farmer confirmed reception of an SMS from the startup, we asked whether he (or she) had read the whole message and had integrated the information and knowledge into their wheat production management. We also asked whether the treated farmers had ever contacted the technician identified in the SMS as being available to answer additional inquiries or provide additional support.

Based on the information collected during the two surveys, this study constructed a longitudinal dataset at the household and plot level. The final dataset consisted of 161 farmers and 612 plots and contained detailed information concerning the farmers' wheat production management.[2] At the end, a total of 116 plots belonging to 31 farmers received site-specific field production management services from the startup through ICT-based technologies, accounting for 19.0% (116 of 612) of the plots sampled in the present study.

When piloting farmer services in the villages, the startup targeted 'larger' farms who were more responsive to ICT-based advisories. Table 2 summarizes the characteristics of both the treated and control farmers before the treated farmers received advisory services. Meanwhile, the two-sample *t*-tests were used to estimate the difference in

[1] The startup first developed an applet and mini-program on WeChat, a popular social media free messaging application in China. However, a survey showed that not every farmer had a smartphone and some were still using conventional mobile phones.

[2] Some farmers refused (or were unable) to take part in the follow-up survey, and this led to an average attrition rate of nearly 30%. To ensure that the dataset was balanced in both the baseline and intervention period, we removed the baseline data corresponding to the samples missing in the follow-up survey.

Table 1 The steps of the short message service (SMS)-based services provided by the startup

No.	Technical project	Parameter/Instrument	Guiding item	In-field guidance	Short messages (date)
1	Soil analysis I	Soil acidity and alkalinity	Formula of fertilizer at basal stage	The adjustment of fertilizer use at the basal stage according to the soil salinity as well as soil acidity and alkalinity; neutral and weak acid fertilizer were advised.	Yes (Sep. 22, 2016)
		Total salinity content	Selection of seed varieties	Salt tolerance/resistant variety/high-yield and high-quality variety.	Yes (Sep. 27, 2016)
2	Meteorological monitoring	Mean daily temperature/Accumulated temperatures	Sowing date and rate	Optimum sowing date in local area; recommended sowing rate.	Yes (Sep. 30/Oct. 8, 2016)
3	Soil analysis II	Full nitrogen	Formula of fertilizer at basal stage	Apply fertilizer according to nutrient content in soil; apply fertilizer with low chlorine content, and avoid using alkaline fertilizer such as diammonium phosphate.	Yes (Oct. 25, 2016)
		Available phosphorus content			
		Available kalium content			
		Organic matter			
4	Field management	Irrigation	Crop management before winter	Irrigate according to soil moisture.	Yes (Nov. 24, 2016)
		Pest prevention		Some advices for the prevention and control of kanazawa spider mites are put forward.	Yes (Dec. 7, 2016)
		Crop population at reviving stage of wheat	Irrigation; formula-type fertilizer and N rates at top-dressing stage	Postpone the irrigation time and fertilizer time at top-dressing stage to jointing stage according to the spring temperatures.	Yes (Feb. 19, 2017)
				The plot with the greatest tiller number (900 m^{-2}) requires N fertilizer to be applied twice: first during the reviving stage (52.5 kg N ha^{-1}) and again during the jointing stage (60 kg N ha^{-1}). An average of 112.5 kg N ha^{-1} was used at the reviving stage in total tiller number with a range from 900 to 1 200 m^{-2}. Across all plots with the total tiller number ranging from 1 200 to 1 500 m^{-2}, an average of 112.5 kg N ha^{-1} was applied at the jointing stage; spraying leaf fertilizer such as Mono Potassium Phosphate.	Yes (Mar. 16, 2017)

means of farm characteristics between the treated and control farmers. The land cultivated by treated farmers was on average 4.5 ha. This was five times bigger than that cultivated by farmers in the control group. The household head of the treated farmers is younger than that of control farm. Other than the farm size and the age of household head, no significant differences in demographic characteristics were identified between the treated and control farmers in the baseline survey. In other words, for the pilot stage of the ICT-based advisory services of agroecological fertilizer management, the startup focused on larger farms.

2.3. Model specification

Many factors that were not controlled by the study could influence farmer's N-fertilizer use, hence a multivariate econometric model was used to estimate the impacts of site-specific services on farmers' N-fertilizer use:

$$DeltaN_{ijk}=\beta_0+\beta_1\text{ICT-based service}_{ijk}+\beta_2\text{Farm size}_i+\beta_3\text{ICT-based service}_{ijk}\times\text{Farm size}_i+\beta_4\text{HH}_i+\mu_{ijk}$$

where $DeltaN_{ijk}$ is the outcome variable of interest and is measured in six ways, which represents the difference between N-fertilizer used in wheat production in two cropping seasons, 2015/2016 and 2016/2017. First, the $DeltaN_{ijk}$ are three binary variables, which equal 1 when the farmer i used less N-fertilizer in plot j in 2016/2017 than that in 2015/2016, otherwise 0. That is, the reduction of nitrogen fertilizer use in the cropping season (k=1), at the basal stage (k=2), and at the top dressing stage (k=3). Second, in addition to the binary measures, three continuous variables were used: total N-fertilizer use per hectare in the cropping season (k=1), at the basal stage (k=2), and at the top dressing stage (k=3). The intervention of site-specific advisory services facilitated by ICTs were delivered to farmer i on two plots j (j=1, 2) under wheat.

The key independent variable of interest on the right side of the equation, ICT-based service_{ijk}, is a binary variable. It

Table 2 Farm characteristics by research design in 2016[1)]

Farm characteristics	Treated farms (*n*=31)	Control farms (*n*=130)	Mean difference	*T*-values	*P*-values
Farm size (ha)	4.51	0.93	–3.58***	–5.23	0.00
Age of household head (year)	52.10	56.01	3.96**	2.32	0.02
Education of household head (year)	7.5	6.8	–0.70	–1.02	0.31
Share of off-farm labor (%)	32.5	32.6	0.12	0.02	0.98
Asset per household (×10³ CNY)	170.8	131.8	–38.98	–1.51	0.13
Size of household (person)	4.3	4.0	–0.32	–0.97	0.33

[1)] All numbers in this table are averages. The last three columns provide two-sample *t*-tests to estimate the difference in means between the treated and control farmers. Source: authors' survey.
** and *** indicate statistically significant at the 5 and 1%, respectively.

equals 1 when farm *i* and plot *k* received the site-specific services from the startup, otherwise 0. The ICT-based advisory services included soil analyses, crop population, and SMS-based communication and advisory services throughout the wheat production season. To explore the effects of land consolidation and farm size on N-fertilizer use, the model included the variable Farm $size_i$. The interaction term between ICT-based $service_{ijk}$ and Farm $size_i$ was used to examine the heterogenous treatment effects of the advisory service on N-fertilizer use. The model also included the vector HH_i to control for additional farmer-level characteristics. To test whether N-fertilizer use in the baseline period affected the reduction in the following year, we included rational use of N-fertilizer in the baseline period in the estimation. It is a binary variable, 1 when N-fertilizer use — be it overall or at different growth stages — in the baseline year by farmer *i* fell within the optimal range; otherwise 0. For other control variables, age and education were measured in years for the household head, and share of off-farm labor was measured in percentage. Township dummy variables were used to control for territorial variations. The term μ_{ijk} is the specific stochastic disturbance and is assumed to be subject to identical independent distribution. A logit model and a fixed effects model were employed to estimate the above equation; the results are presented in Section 3.2. The descriptive statistics for all variables are presented in Table 3.

3. Results

3.1. Description analysis

The problem of excessive N-fertilizer use appeared to be less significant than that reported in previous research. Table 4 presents N-fertilizer use and the mean difference of N management between the treated and control farms. It shows that farmers applied N-fertilizer twice on average and there was no significant difference between the large treated farms and the control small farms. Prior to the entrepreneurial pilot project, the treated farmers used 265.6 kg N ha^{-1} for wheat production (i.e., less than 30% excess). For the control farmers, the excess was higher (90 kg N ha^{-1}, about 45% of the recommended amount). Other studies conducted in Shandong reported an even higher rate of overuse of N-fertilizer in wheat production, such as 365 kg N ha^{-1} in 2003 (Cui 2005) and 357–380 kg N ha^{-1} between 2008 and 2010 (Jia *et al.* 2015).

Overall use of N-fertilizer by both the treated and control farmers for wheat production declined, and the reduction was greater on the treated farms. As shown in Table 4, about 65.52% of the treated farmers reduced their overall N-fertilizer use, while the reduction was slightly less (60.34%) on the control farms. It should be noted that total N-fertilizer use on the treated farms (265.60 kg ha^{-1}) was lower than that on the control farms (290.80 kg ha^{-1}) in the baseline year, possibly because of the difference in the size of the farms. Considering an already lower level of N-fertilizer use by the treated farms (relative to the control farms), the reduction of 41.66 kg ha^{-1} (223.94–265.60 kg ha^{-1}) — equivalent to 15.7% saving — is significant compared with the equivalent reduction of 11.3% on the smaller control farms.

The behavioral changes in nitrogen management on the treated and control farms became clearer when the N-fertilizer use was broken down into different wheat growth stages. As shown in Table 4, farmers in the study area used more nitrogen before the top dressing stage in the baseline year. For example, on the treated farms, about 40% (105.15 of 265.60 kg ha^{-1}) of N-fertilizer was used in the early stage and the remaining 60% was used after jointing in the baseline year. The proportion did not differ significantly on the control farms in the baseline year. In the treatment year, the rates of N-fertilizer used at different growth stages approached the recommended rates on the treated farms, 109.81 and 114.13 kg ha^{-1}, respectively. The ICT-based services thus appeared to be effective. On the control farms, the rates of N-fertilizer use before and after jointing remained 117.04 and 140.89 kg ha^{-1}, respectively.

Table 3 Descriptive statistics on all the variables

Variable	Average		2015/2016		2016/2017	
	Mean	SD	Mean	SD	Mean	SD
Full growth period N-fertilizer (kg ha^{-1})	268.8	104.2	286.0	99.4	251.5	106.2
Basal stage N-fertilizer (kg ha^{-1})	108.1	55.0	100.5	44.3	115.7	63.1
Top dressing stage N-fertilizer (kg ha^{-1})	160.7	88.6	185.6	93.9	135.8	75.2
ICT-based services (Yes=1; No=0)	0.1	0.3	0	0	0.2	0.4
Farm size (ha)	1.5	3.3	1.5	3.2	1.5	3.4
Age of household head (year)	55.7	8.6	55.2	8.6	56.2	8.6
Education of household head (year)	7.0	3.4	7.0	3.4	7.0	3.4
Share of off-farm labor (%)	32.4	24.9	32.8	25.1	32.0	24.7
Reduced N-fertilizer use in all growth period (Yes=1; No=0)	0.6	0.5	–	–	0.6	0.5
Reduced N-fertilizer use at basal stage (Yes=1; No=0)	0.4	0.5	–	–	0.4	0.5
Reduced N-fertilizer use at top dressing stage (Yes=1; No=0)	0.6	0.5	–	–	0.6	0.5
Rational use of N-fertilizer in the baseline all growth period (Yes=1; No=0)	0.6	0.5	–	–	0.6	0.5
Rational use of N-fertilizer in the baseline (basal stage) period (Yes=1; No=0)	0.4	0.5	–	–	0.4	0.5
Rational use of N-fertilizer in the baseline (top dressing) period (Yes=1; No=0)	0.6	0.5	–	–	0.6	0.5

Table 4 N-fertilizer use by treated and control farmers for wheat production in the 2015–2016 and 2016–2017 cropping seasons[1)]

	Treated farms' plots (*n*=116)	Control farms' plots (*n*=496)	Mean difference	*T*-values	*P*-values
Number of fertilizer applications					
2015–2016	2.07	2.21	0.14***	3.48	0.00
2016–2017	2.03	2.05	0.02	0.49	0.62
Full growth period N-fertilizer (kg ha^{-1})					
2015–2016	265.60	290.80	25.20**	2.47	0.01
2016–2017	223.94	257.93	33.99***	3.13	0.00
Basal stage N-fertilizer (kg ha^{-1})					
2015–2016	105.15	99.35	–5.79	–1.27	0.21
2016–2017	109.81	117.04	7.23	1.11	0.27
Top dressing stage N-fertilizer (kg ha^{-1})					
2015–2016	160.45	191.45	30.99***	3.23	0.00
2016–2017	114.13	140.89	26.76***	3.48	0.00
Incidence of N-reduction (%)					
Total N-fertilizer	65.52	60.08	–5.44	–1.08	0.28
Basal stage N-fertilizer	48.28	35.08	–13.20***	–2.65	0.01
Top-dressing stage N-fertilizer	60.34	65.73	5.38	1.09	0.28

1) N-fertilizer means pure nitrogen content. The last three columns provide two-sample *t*-tests to estimate the difference in means between the treated and control farmers. Source: authors' survey.
** and *** indicate statistically significant at the 5 and 1%, respectively.

3.2. Multivariate analysis

Multivariate analysis shows robust evidence of farmers' adaptive and partial compliance with the ICT-based advisory. The estimated coefficient of the variable ICT service was 0.21 (38–17%), and it was positive and statistically significant (Table 5, column 1). All other factors being constant, farmers who received services from the startup had a 38% higher probability of reducing N-fertilizer use than the control farmers. When further examining N-fertilizer use at different growth stages (i.e., at the basal stage in column 2 and at the top dressing stage in column 3), the effects were also significant, indicating behavioral changes in nitrogen management that are more site-specific and adapted to local characteristics and variations. Despite behavior changes towards site-specific and adaptive N-fertilizer management, it is interesting that the overall and by-stage N-fertilizer use did not reduce significantly (Table 6). This indicates a partial adoption of ICT-based farming advisory.

The effects on individual farmers' wheat production pipelined by the startup were heterogeneous according to farm size. The estimated coefficient on the interaction of ICT services with farm size was negative and statistically significant, implying that *ceteris paribus* one additional hectare in farm size decreased the probability of reducing

N-fertilizer use by 17% (Table 5, column 1, row 3). In other words, the probability of N-fertilizer reduction on large farms was lower than that on small farms. It is partly because the larger farms had already used lower rates of N fertilizer than small farmers because of their more professional farm management decisions in the baseline period (Huang *et al.* 2012).

Improved nitrogen management had a positive effect on wheat production. As seen in Table 7, the average yield obtained by the treated farmers was 7.38 t ha^{-1} in the baseline year, which increased to 7.84 t ha^{-1} (i.e., a 6.2% increase in yield) in the 2016–2017 cropping season. Similar effects were observed for the control farmers but the magnitude of the increase (3.0%) was slightly lower than that obtained by the treated farmers. Given that the ICT-based advisory services did not significantly reduce the overall nitrogen use, the positive effects on yield for the treated farmers were mostly attributed to variable-rate N-fertilizer use at different crop growth stages and site-specific management.

The survey asked the treated farms about their communication and interactions with the startup or with the extension agents in the county identified in the messages. Only 5% of the treated farmers reported a strong motivation and follow-up contact for additional inquiries concerning problems or solutions. A similar finding was reported in a recent study on Chinese farmers' compliance with agricultural production standards (Ding *et al.* 2019). All surveyed farmers were also asked about their information exchange with other farmers in the villages. The reported rates of such communications were surprisingly low. In fact, most farmers obtained farming advisory from agro-inputs dealers who may oversell the use of fertilizers.

Financial sustainability is at the heart of the challenges facing the entrepreneurial innovations we studied. The ICT-based advisory services potentially produce economic benefits of 90 US$ per hectare (i.e., about 40 CNY per Chinese mu, 1 mu=1/15 ha) by saving the cost of fertilizer and increasing yield. Given the small average farm size, farmers' interest and incentives to participate in low-carbon practices are limited; the average profit obtained by applying nitrogen optimization

Table 5 Estimated reduction in N-fertilizer use in 2015–2016 and 2016–2017 wheat production in Shandong, China (Logit model)[1)]

	Reduced N-fertilizer use (1=Yes; 0=No)		
	Overall (1)	Basal stage (2)	Top dressing stage (3)
ICT-based services (Yes=1; No=0)	0.38***	0.43***	0.26***
	(0.061)	(0.106)	(0.066)
Farm size (ha)	0.13***	0.06*	0.07**
	(0.042)	(0.035)	(0.034)
Interaction terms of ICT-based services and farm size	–0.17***	–0.10**	–0.12***
	(0.044)	(0.038)	(0.042)
Control variables			
Rational use of N-fertilizer in the baseline period (Yes=1; No=0)	–0.61***	–0.55***	–0.69***
	(0.061)	(0.058)	(0.056)
Age of household head (year)	0.01*	0.01***	–0.00
	(0.004)	(0.004)	(0.004)
Education of household head (year)	–0.00	0.01	–0.01
	(0.011)	(0.009)	(0.011)
Share of off-farm labor (%)	0.00	0.00	–0.00***
	(0.002)	(0.001)	(0.002)
Control township dummy	Yes	Yes	Yes
Pseudo R^2	0.25	0.22	0.35

1) The total number of observations is 306. Township dummies were controlled but they were not reported here.
Robust standard errors in parentheses; *, **, and *** indicate statistically significant at the 10, 5, and 1%, respectively.

Table 6 Estimated farmers' use of N-fertilizer for wheat production in the 2015–2016 and 2016–2017 in Shandong, China (Fixed-effects models)[1)]

	N-fertilizer (kg ha^{-1})		
	Overall (1)	Basal stage (2)	Top-dressing stage (3)
ICT-based services (Yes=1; No=0)	–8.84	–18.03	9.19
	(0.50)	(1.46)	(0.56)
Farm size (ha)	–12.26***	–0.80	–11.47***
	(3.85)	(0.27)	(4.86)
Interaction terms of ICT-based services and farm size	0.76	1.68	–0.92
	(0.46)	(1.17)	(0.65)
Control variables			
Age of household head (years)	–33.15***	16.94***	–50.09***
	(3.74)	(3.45)	(6.71)
Share of off-farm labor (%)	–0.57	–0.57	–0.009
	(0.81)	(1.24)	(0.00)
Constant	2 152.29***	–815.00***	2 967.29***
	(4.39)	(3.00)	(7.14)
R^2	0.083	0.056	0.185

1) The total number of observations is 612.
Absolute values of *t*-ratio in brackets; *** indicate statistically significant at 1%.

Table 7 Farm wheat yields (t ha^{-1}) in the 2015–2016 and 2016–2017 cropping seasons[1)]

Season	Treated farms' plots (*n*=116)	Control farms' plots (*n*=496)	Mean difference	*T*-values	*P*-values
2015–2016	7.38	7.24	–0.14	–1.20	0.23
2016–2017	7.84	7.46	–0.38***	–3.44	0.00

1) The last three columns provide two-sample *t*-tests to estimate the difference in means between the treated and control farmers. Source: authors' survey.
*** indicates statistically significant at 1%.

technologies would be only 264 CNY per farm, equivalent to 40 US$ for the whole wheat cropping season.[3] The financial sheet obtained from the startup further indicated that the operating cost of the project was 98 US$ per farm for the site-specific advisory services, including personnel, utilities, R&D and overhead costs. After adding the costs relating to soil analyses, crop population and other site-specific diagnoses, which were financed by the National Research Program, the unit cost of delivering the ICT-based advisory services totaled almost 150 US$ per farm. These costs are almost twice higher than other community-based and participatory approaches such as Farmer Field Schools (FFS).[4] ICT-based agroecological services thus seem to be a "heavy-touch" and resource-intensive solution to agricultural sustainability.

4. Discussion

This study confirms the heterogeneous effects of ICT-based services by farm size. The entrepreneurial venture was inclined to target 'larger' farms. However, large farms were 'risk-averse' than small farmers when being advised to significantly reduce N-fertilizer use. They may pilot new technologies first on one or two individual plots and then scale up the practices after the effects are verified after several seasons. This is in agreement with the results of Ma and Zheng (2021), who reported the heterogeneous impacts of smartphone-based information use. Large farmers were found to be 'shrewd' in N-fertilizer use given greater cost relating to fertilizer use; they are more interested in and participatory in adopting efficiency-enhancing technologies, such as nitrogen optimization.

The findings indicate a dynamic process of adopting sustainable practices in agriculture, from partial adoptions to a full behavior change. The results show limited impact on full adoption of the recommendation of site-specific N-fertilizer. As found in a few studies, technology adoption is a deliberate decision that demands attention, and occasionally those intentions are lost in the shuffle, buried by everyday distractions (Larochelle *et al.* 2019; Carrión-Yaguana *et al.* 2020). Text messaging provides new avenues for farmers to get information and reminders, and it can improve and increase the adoption rate of technology practices (Stocwell *et al.* 2012). However, the complex concept of site-specific and time-variant N-fertilizer use is not easily conveyed *via* ICT (Steinke *et al.* 2021). The effects of ICT-based services on farmers' decision-making are often intermediate, and the process is dynamic and social, involving adaptive learning and trust (Aker *et al.* 2016).

Our analysis of the effectiveness of ICT-based farmer services and financial sustainability calls for deeper thinking and debate about the organizational identity of startups that combines the interest of the public and private sectors. The startup registered itself as a private company providing agribusiness and technological services; venture capital was the primary external resource of capital. While the startup is profit driven and mainly responsible to the shareholders and equity investors, the agroecological services generated significant environmental value and moderate developmental effects (for smallholder farmers). This blending of profit-driven business and social mission goes beyond the conventional concept of socially responsible behavior in the private sector (such as corporate social responsibility). As Dacin *et al.* (2011) indicated, from the global perspective the concept of social entrepreneurship, an emerging phenomenon and new financial tools, are facilitating entrepreneurial innovations that address persistent social and environmental problems. Social entrepreneurship, by definition, is primarily mission driven and adopts hybrid business strategies by "doing good and doing well". The startup we studied in this case does not seem to fit this definition. The Chinese government has made tremendous efforts to encourage entrepreneurial innovations (called Mass Entrepreneurship and Mass Innovations) to unleash the growth potential of the economy. While most initiatives are implemented in the business sectors, the government could consider promoting and incentivizing more private capital to invest in entrepreneurial innovations tackling social and environmental problems. In the era of digital revolution in agriculture, a new governance form of public–private entrepreneurship is up and coming (Qiang *et al.* 2009).

This anecdotal study projects a trajectory of reconfiguring China's farming system towards resilience and sustainability in the digital era. While the farming system is being transformed from the private to the public sphere, external stakeholders have become increasingly involved in the internal farm operations, the decision making and knowledge exchange (Noe and Alrøe 2011). The development of ICTs and the Internet of Things (IOTs) can transform agriculture by translating tacit knowledge that was not previously communicated into

[3] The average farm size was 0.44 ha in the local area in 2016.

[4] The unit cost of FFS was estimated at 80 US$ per farm for an integrated farm management with a thematical highlight of nitrogen management in China (Guo *et al.* 2015).

codified information. However, technological innovations such as ICTs or IOTs should not be applied based on the desire for “control-and-command”, but rather on the desire to mobilize a collective and distributed intelligence more efficiently than the discipline-based individual approaches (Menard and Casabianca 2011). In this exemplary case, the entrepreneurial startup networks the national research capacities and individual farmers through ICTs. Nevertheless, the engagement of individual farmers was not participatory, nor was local extension capacities involved. Such a business model does not fit agroecological approaches that seek to reach locally acceptable and adaptable solutions. The advancement of communication and digital technologies needs to make the system ‘smart’ responsive and adaptive to the disturbance caused by promoting learning and socio-technical governance, rather than providing a linear way of centralized decision-making by technical authorities, be they public or private.

What does China learn from the Project on reforming its national research support on agricultural sustainability and digitalization? A total of US$ 363.6 million was budgeted and delivered through 49 projects of the National Research Program throughout 2016 and 2018 to promote applied research and technology development dealing with excessive agrochemicals use in agriculture. However, very lean resources were invested in searching for ‘innovations’ from societal and management perspectives. This study and numerous other studies suggest that sectoral innovations and sustainability transitions only occur when the ‘social’ (e.g., human advisory and field facilitators) and ‘technical’ (e.g., digital services) aspects of innovations can collaboratively identify a diverse set of system weaknesses (Jacobsson and Bergek 2011). The reconfiguration of China’s farming systems will be impossible if the process is independent of the reform of the socio-technical regime and the inspiration of a culture conducive to scientist-led entrepreneurship. After all, putting technological innovations into practice requires experiment, outreach, adaption, and collaborations, and such a process needs to include a range of actors regardless of their technological capacities (Jacobsson and Bergek 2011).

The present study has some limitations. Firstly, this study did not investigate the mechanism that influences farmers’ behavior change, such as knowledge about fertilizer. If farmers are “told” to adopt fertilizer practices without increasing internalized knowledge, the sustainability of their input use may still be a concern. Secondly, although fixed effect (FE) model was used, the endogeneity problem was not completely overcome because of the surveyed sample. However, unlike some previous studies of randomizing farmer services (Huang *et al.* 2015), this study took a different approach of action research and did (and could) not introduce an experimental research design. Observing the real behavior and strategies of businesses was part of the research objectives. Thirdly, surveyed details of the cost of fertilizer and dissemination (such as labor and opportunity cost) were not sufficient for additional analysis. The research interest of economic impacts associated with reduced fertilizer use can be referred to some other studies such as Cole and Fernando (2021). Lastly, it is likely that conducting survey may have an impact on farmers’ nitrogen fertilizer use behavior (so-called, Hawthorne effect). Although such a distortion would be similar for both treated and control farmers, it might affect the rates of N-fertilizer.

5. Conclusion

Excessive fertilizer use has been a significant concern in China’s agricultural sustainability, and ICT opens wider opportunities to address associated problems. This case study is the first to document the operation of an entrepreneurial startup financed by venture capital. It examines the effectiveness of ICT-based farmer services for nitrogen management in wheat production in the North China Plain. This study found genuine changes in sustainable farm practices through ICT-facilitated services. Nevertheless, the service provider showed a biased interest by serving ‘large’ farms as they opt for pioneering new technologies and are more entrepreneurial. While the smallholder farms seemed to be benefiting from reducing N-fertilizer use and adopting nitrogen optimization in wheat production, they may not be the targeting users for the business entrepreneurs. Farmer services of sustainable practices by high-tech startups may not suit the self-sufficient or semi-self-sufficient farmers. Additional institutions and public extension services should be complementary, and entrepreneurial innovations may not be the mainstream or backbones for China to transform its agriculture towards sustainability.

Acknowledgements

We are grateful to the members of the survey team who worked hard to collect the data. We acknowledge financial support from the National Natural Science Foundation of China (72003148), the Agricultural Science and Technology Innovation Program of the Chinese Academy of Agricultural Sciences (CAAS-ASTIP–2016-AII), the Chinese Universities Scientific Fund (2452020072), the National Key Research and

Development Program of China (2016YFD0201303).

Declaration of competing interest

The authors declare that they have no conflict of interest.

References

Aker J C. 2011. Dial "A" for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, **42**, 631–647.

Aker J C, Ghosh I, Burrell J. 2016. The promise (and pitfalls) of ICT for agriculture initiatives. *Agricultural Economics*, **47**, 35–48.

Van Campenhout B, Spielman D J, Lecoutere E. 2021. Information and communication technologies to provide agricultural advice to smallholder farmers: Experimental evidence from Uganda. *American Journal of Agricultural Economics*, **103**, 317–337.

Carrión-Yaguana V D, Alwang J, Barrera V H. 2020. Promoting behavioral change using text messages: A case study of blackberry farmers in Ecuador. *Journal of Agricultural and Applied Economic*, **52**, 398–419.

Chen D D, Qu H R, Cao H Z, Wang H D, Ma W Q. 2016. Study on recommendation of top-dressing nitrogen fertilizer technologies for different growth status of winter wheat seeding. *Journal of Triticale Crops*, **36**, 624–630. (in Chinese)

CNNIC (China Internet Network Information Center). 2016. *The Research Report of the Development of Internet in Rural China in 2015*. pp. 1–36.

Cole S, Fernando A N. 2021. 'Mobile'izing agricultural advice: Technology adoption, diffusion and sustainability. *The Economic Journal*, **131**, 192–219.

Cui Z L. 2005. Optimization of the nitrogen fertilizer management for a winter wheat-summer maize rotation system in the North China Plain from field to regional scale. Ph D thesis, China Agricultural University, Beijing. (in Chinese)

Cui Z L, Zhang F S, Chen X P, Miao Y X, Li J L, Shi L W, Xu J F, Ye Y L, Liu C S, Yang Z P, Zhang Q, Huang S M, Bao D J. 2008. On-farm evaluation of an in-season nitrogen management strategy based on soil N_{min} test. *Field Crops Research*, **105**, 48–55.

Dacin M T, Dacin P A, Tracey P. 2011. Social entrepreneurship: A critique and future directions. *Organization Science*, **22**, 1203–1213.

Ding J P, Moustier P, Ma X P, Huo X X, Jia X P. 2019. Doing but not knowing: How apple farmers comply with standards in China. *Agriculture and Human Values*, **36**, 61–75.

Duveskog D, Mbura C, Critchley W. 2003. Harnessing indigenous knowledge and innovation in farmer field school. In: CIP-UPWARD, *Farmer Field Schools: Emerging Issues and Challenges*. International Potato Center-Users' Perspectives with Agricultural Research and Development (UPWARD), Los Banos, Laguna, Philippines. pp. 197–209.

FAO (Food and Agriculture Organization of the United Nations). 2021. Online overview: Climate-smart agriculture. [2021-9-25]. http://www.fao.org/climate-smart-agriculture/overview/en/

Guo J H, Zhang Y, Shen J L, Han W X, Zhang W F, Christie P, Goulding K W T, Viyousek P M, Zhang F S. 2010. Significant acidification in major Chinese croplands. *Science*, **327**, 1008–1010.

Guo M L, Jia X P, Huang J K, Krishna K, Nicholas B. 2015. Farmer field school and farmer knowledge acquisition in rice production: Experimental evaluation in China. *Agriculture, Ecosystems & Environment*, **209**, 100–107.

Huang J K, Huang Z R, Jia X P, Hu R F, Xiang C. 2015. Long-term reduction of nitrogen fertilizer use through knowledge training in rice production in China. *Agriculture System*, **135**, 105–111.

Huang J K, Xiang C, Jia X P, Hu R F. 2012. Impacts of training on farmer's nitrogen use in maize production in Shandong, China. *Journal of Soil and Water Conservation*, **67**, 321–327. (in Chinese)

Jacobsson S, Bergek A. 2011. Innovation system analyses and sustainability transitions: Contributions and suggestions for research. *Environmental Innovation and Societal Transitions*, **1**, 41–57.

Jensen R. 2007. The digital provide: Information (technology), market performance, and welfare in the South Indian fisheries sector. *The Quarterly Journal of Economics*, **122**, 879–924.

Jia X P. 2017. *Venture Capital and Entrepreneurial Innovation in China's Agriculture*. Economy & Management Publishing House, Beijing. (in Chinese)

Jia X P, Huang J K, Xiang C, Bergmann H, Zhang F. 2013. Farmer's adoption of improved nitrogen management strategies in maize production in Shandong of China: An experimental study. *Journal of Integrative Agriculture*, **12**, 364–373.

Jia X P, Huang J K, Xiang C, Powlson D. 2015. Reducing excessive nitrogen use in Chinese wheat production through knowledge training: What are the implications for the public extension system? *Agroecology and Sustainable Food Systems*, **39**, 189–208.

Kahrl F, Li Y J, Su Y F. 2010. Greenhouse gas emissions from nitrogen fertilizer use in China. *Environmental Science & Policy*, **13**, 688–694.

Kaila H, Tarp F. 2019. Can the Internet improve agricultural production? Evidence from Vietnam. *Agricultural Economics*, **50**, 675–691.

Larochelle C, Alwang J, Travis E, Barrera V H, Dominguez J M. 2019. Did you really get the message? Using text reminders to stimulate adoption of agricultural technologies. *The Journal of Development Studies*, **55**, 548–564.

Ma W L, Zheng H Y. 2021. Heterogeneous impacts of information technology adoption on pesticide and fertilizer expenditures: Evidence from wheat farmers in China. *The Australian Journal of Agricultural and Resource Economics*, **59**, 1–21.

Matson P A, Naylor R, Ortiz-Monasterio I. 1998. Integration of environmental, agronomic, and economic aspects of fertilizer management. *Science*, **280**, 112–115.

Meynard J M, Casabianca F. 2013. Agricultural systems and the innovation process. In: Bouche R, Derkimba A, Casabianca F, eds., *New Trends for Innovation in the Mediterranean Animal Production*. Wageningen Academic Publishers, Wageningen. pp. 17–26.

NBSC (National Bureau of Statistics of China). 2016. *China Statistics Yearbook in 2016*. China Statistics Press, Beijing. (in Chinese)

Noe E, Alrøe H F. 2011. Quality, coherence and co-operation: A framework for studying the mediation of qualities in food networks and collective marketing strategies. *The International Journal of Sociology of Agriculture and Food*, **18**, 12–27.

Norse D, Powlson D S, Lu Y L. 2012. Integrated nutrient management as a key contributor to China's low-carbon agriculture. In: Wollenberg E, Nihart A, Tapio-Bistrom M L, Grieg-Gran M, eds., *Climate Change Mitigation in Agriculture.* Earthscan, Abingdo. pp. 347–359.

Powlson D, Norse D, Chadwick D, Lu Y L, Zhang W F, Zhang F S, Jia X P. 2014. Contribution of improved nitrogen fertilizer use to development of a low carbon economy in China. *World Agriculture*, **4**, 10–18.

Qiang C Z, Bhavnani A, Hanna N K, Kimura K, Sudan R. 2009. Rural informatization in China. World Bank Working Paper. No. 172. pp. 1–70.

Rao S S. 2008. Social development in Indian rural communities: Adoption of telecentres. *International Journal of Information Management*, **28**, 474–482.

Silvia S, Richard M, Edward B, Dharmesh G, Dannie R. 2021. Going digital in agriculture: How radio and SM can scale-up smallholder participation in legume-based sustainable agricultural intensification practices and technologies in Tanzania. *International Journal of Agricultural Sustainability*, **19**, 583–594.

Sinclair T R, Rufty T W. 2012. Nitrogen and water resources commonly limit crop yield increases, not necessarily plant genetics. *Global Food Security*, **1**, 94–98.

Steinke J, Van Etten J, Müller A, Ortiz-Crespo B, van de Gevel J, Silvestri S, Priebe J. 2021. Tapping the full potential of the digital revolution for agricultural extension: An emerging innovation agenda. *International Journal of Agricultural Sustainability*, **19**, 549–565.

Stockwell M S, Kharbanda E, Martinez R, Vargas C Y, Vawdrey D K, Camargo S. 2012. Effect of a text messaging intervention on influenza vaccination in an urban, low-income pediatric and adolescent population: A randomized controlled trial. *JAMA*, **307**, 1702–1708.

Sunding D, Zilberman D. 2001. The agricultural innovation process: Research and technology adoption in a changing agricultural sector. In: Gardner B, Rausser G, eds., *Handbook of Agricultural Economics*. Elsevier, Amsterdam, North Holland. pp. 207–261.

Tilman D, Cassman K G, Matson P A, Naylor R, Polasky S. 2002. Agricultural sustainability and intensive production practices. *Nature*, **418**, 671–677.

Vitousek P M, Naylor R, Crews T, David M B, Drinkwater L E, Holland E, Johnes P J, Katzenberger J, Martinelli L A, Matson P A, Nziguheba G, Ojima D, Palm C A, Robertson G P, Sanchez P A, Townsend A R, Zhang F S. 2009. Nutrient imbalances in agricultural development. *Science*, **324**, 1519–1520.

Wu H J, MacDonald G K, Galloway J N. 2021. The influence of crop and chemical fertilizer combinations on greenhouse gas emissions: A partial life-cycle assessment of fertilizer production and use in China. *Resources, Conservation and Recycling*, **168**, 105303.

Zhang F S, Chen X P, Chen Q. 2009. *Handbook of Fertilization of Major Cash Crops in China*. China Agricultural University Press, Beijing. (in Chinese)

Zhang W F, Dou Z X, He P, Ju X T, Powlson D S, Chadwick D R, Norse D, Lu Y L, Zhang Y, Wu L, Chen X P, Cassman K G, Zhang F S. 2013. New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. *Proceedings of the National Academy of Science of the United States of America*, **110**, 8375–8380.

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