Factors influencing the farmer's chemical fertilizer reduction behavior from the perspective of farmer differentiation

Shan Zheng a, Keqing Yin b,*, Lianghong Yu a

a Management College, Ocean University of China, Qingdao 266100, PR China
b Peninsula Media of Popular Newspaper Group, PR China

ARTICLE INFO

Keywords:
Farmer
Chemical fertilizer reduction application
Influencing factors
Farmer differentiation
Structural equation model

ABSTRACT

Farmers are the primary decision-makers in chemical fertilizer application. Identifying their chemical fertilizer reduction behavior and its influencing factors is critical to controlling the surface source pollution caused by excessive fertilizer. This paper incorporates farmer characteristic, technology cognition and social capital into the analytical framework of farmers' fertilizer reduction behavior. Based on 889 farmers' questionnaire data, this paper constructs a Structural Equation Model to analyze farmers' fertilizer reduction behavior and its influencing factors from the perspective of farmers' differentiation. The findings are as follows. (1) Farmer characteristics, technology cognition and social capital all positively influence farmers' chemical fertilizer reduction behavior. Among them, social capital has the highest degree of influence on farmers' chemical fertilizer reduction behavior followed by farmer characteristics, while technology cognition shows the lowest influence. (2) The effect of technology cognition on small-scale pure farmers' chemical fertilizer reduction behavior is insignificant. However, the effect on part-time farmers and large professional farmers is significant, and the effect is higher for large professional farmers. (3) The effect of farmer characteristics on part-time farmers' chemical fertilizer reduction behavior is insignificant. However, the effect on small-scale pure farmers and large professional farmers is significant, and the effect is higher for large professional farmers. (4) The effect of social capital on chemical fertilizer reduction behavior of small-scale pure farmers, part-time farmers, and large professional farmers is significant. This effect is the highest for part-time farmers, followed by large professional farmers, and the lowest for small-scale pure farmers. Accordingly, to continuously promote chemical fertilizer reduction, the government should focus on strengthening policy support, technical support, education guidance and classification.

1. Introduction

Under the traditional development model of relying solely on intensive agricultural inputs to obtain high yields, excessive chemical fertilizer application increases the cost of agricultural production [1], and its negative externalities lead to the growing problem of agricultural surface pollution [2], which restricts the high-quality and sustainable development of agriculture [3]. In terms of total chemical fertilizer application, China's total chemical fertilizer application reached 63.35 million tons in 2021, significantly exceeding the world average level. Although China has basically achieved zero growth in chemical fertilizer application, the total amount of chemical fertilizer application is still high. Therefore, it is urgent to continuously promote the reduction of chemical fertilizer application. In terms of chemical fertilizer application intensity, at present, the average chemical fertilizer application per crop sown area in China is about 362.41 kg/hm², which exceeds the internationally accepted safety limit by 1.61 times¹ and dramatically exceeds the highest alert line required by the Ministry of Environmental Protection of China. Overreliance on chemical fertilizer inputs to obtain high yields is unsustainable [4]. Comprehensively reducing the total amount and intensity of fertilizer application has increasingly become the focus of promoting the green transformation of agriculture and agricultural surface pollution management [5].

Chemical fertilizer reduction has a significant positive externality in reducing environmental pollution and carbon emissions [6]. Governments are always expected to provide incentives for such positive externalities [7, 8, 9]. To this end, China has introduced a series of policies to reduce the amounts of chemical fertilizers. The Ministry of Agriculture

¹ Data Source: Ministry of Agriculture and Rural Affairs “Zero Growth Action Plan for Chemical Fertilizer Use by 2020”.

https://doi.org/10.1016/j.heliyon.2022.e11918
Received 15 April 2022; Received in revised form 4 July 2022; Accepted 17 November 2022
2405-8440/© 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
issued the “Zero Growth Action Plan for Chemical Fertilizer Use by 2020”, which requires zero growth in chemical fertilizer use for major crops by 2020. Central Government No.1 documents in 2021 and 2022 propose the in-depth implementation of chemical fertilizer reduction and efficiency actions. Numerous studies have shown that governments implementing financial subsidies and other forms of support can compensate for the potential loss of profit from reductions [10] and subsequently stimulate reduction behavior [11]. However, studies have also shown that government subsidies are a non-market-based, universal behavioral incentive [12], which can only have a short-term effect and cannot fundamentally change the production habits of farmers [13]. Once government subsidies cease, farmers will carry out agricultural production according to the pre-subsidy fertilizer use [14]. It should not be ignored that farmers are the central subject of fertilizer reduction [15]. From the perspective of farmers, the key to controlling chemical fertilizer application at source is to accurately grasp farmers’ chemical fertilizer reduction behavior and its influencing factors. However, with the deepening of rural reforms and the gradual improvement of rural factor markets, driven by industrialization and urbanization, farm households have begun to differentiate from homogeneity to heterogeneity [16]. Different types of farmers have different endowments and perceptions of agricultural technology, but this is often ignored. Therefore, what are the influencing factors of farmers’ chemical fertilizer reduction? What is the impact of farmer differentiation on chemical fertilizer application reduction? This is the core question of this paper.

This paper constructs a theoretical model of farmer characteristics, technology cognition, social capital and farmers’ chemical fertilizer reduction behavior based on the perspective of farmers’ differentiation. Then, empirically test farmers’ chemical fertilizer reduction behavior and its influencing factors based on 889 farmers’ survey data and Structural Equation Model. On this basis, the impact of farmer differentiation on farmers’ chemical fertilizer reduction behavior is further analyzed. Finally, recommendations to reduce farmers’ chemical fertilizer application are proposed in four aspects: policy support, technical support, education guidance, and categorical measures.

Compared with the existing studies, the marginal contributions of this paper are as follows. First, most of the existing relevant studies have explored the influence of government behavior on fertilizer reduction from a macro perspective [17, 18, 19]. This paper explores the factors influencing the fertilizer reduction behavior of different farmer types from a micro perspective and analyzes the pathways of each influencing factor, further enriching the theory of farmers’ behavior. Secondly, traditional regression methods tend to ignore the problem of multicollinearity in the independent variables, which affects the scientific validity of the research findings. In order to effectively avoid the multicollinearity among the independent variables, this paper adopts Structural Equation Model to estimate the influencing factors of farmers’ fertilizer reduction behavior, enhancing the scientific validity of the research findings. Thirdly, most existing studies treat farmers as a homogeneous group, ignoring the agricultural production preferences of different farmer types. This paper explores the factors influencing the fertilizer reduction behavior of different farmer types, which is conducive to exploring a practical path to promote chemical fertilizer application reduction comprehensively, providing theoretical guidance and practical reference to alleviate agricultural surface source pollution further and promote green and high-quality agricultural development.

2. Literature review

2.1. Research related to chemical fertilizer reduction application

Fertilizers play an essential role in enhancing agricultural productivity, but the current excessive application of chemical fertilizers has caused a series of environmental pollution and eutrophication problems [20, 21, 22, 23]. Under the premise of guaranteeing national food security and agricultural income of farmers, how to reduce the application of chemical fertilizers has become an important issue [24]. In the field of agricultural technology, there are common ways to reduce the application of chemical fertilizers, including the promotion of soil fertility testing techniques, the replacement of chemical fertilizers with organic or biological fertilizers and so on. First, replace chemical fertilizer with organic fertilizer to reduce its use. The soil microbial community composition was changed by substituting organic fertilizer for chemical fertilizer [25], which contributes to optimizing soil ecology. Fachini et al. (2022) found that biochar fertilizers are an excellent alternative to traditional chemical fertilizers due to their poor solubility and minimal risk of contaminating groundwater through leaching [26]. Straw returning can effectively reduce the application of mineral phosphate fertilizer without significantly reducing the cotton yield in coastal saline-alkali land [27], which also protects the quality of surface water [28]. Phosphorus from crop residues is released into the soil and can partially replace chemical phosphorus applications [29]. Organic fertilizers such as cow dung and biological nutrients such as royal jelly can entirely or partially replace chemical fertilizers [30]. Second, biological fertilizer and organic fertilizer combined application. The results showed that partial substitution of organic fertilizer for chemical fertilizer had a positive effect on grain yield of summer maize [31] and can reduce the need for synthetic nitrogen fertilizers while maintaining or increasing rice yields [32, 33]. In vegetable production, biofertilizers are not a complete substitute for chemical fertilizers, but the simultaneous use of chemical, organic and biological fertilizers is more effective for potato growth [34]. In fruit growing, 30% organic fertilizer combined with 70% chemical fertilizer can achieve the dual goals of sustainable productivity and environmental protection in citrus orchards [35]. Proper application of bio-organic fertilizer and chemical fertilizer can improve soil properties and reshape bacterial and fungal ecology, thus improving crops’ yield and quality.

In addition to chemical fertilizer reduction technologies, policies are also an important factor affecting chemical fertilizer reduction application [36], including incentive and penalty policies [37]. In terms of promoting fertilizer reduction, the policy is mainly incentive-based. For instance, Guo et al. (2021) used the control function method and micro farmer data to analyze the positive impact of agricultural subsidies on fertilizer use by Chinese rice farmers [38]. Numerous studies have verified the positive effect of subsidies in promoting farmers’ adoption of new technologies [39]. Contrary to that, some studies have found that increasing subsidies can improve the utilization rate of organic fertilizer, but excessive subsidies are not conducive to sustainable agricultural development [13, 14]. Furthermore, there are other chemical fertilizer reduction influencing factors. For instance, using endogenous conversion models and survey data collected in Xinjiang, Guan et al. (2022) found that collective drip irrigation reduced fertilizer intensity by 10.31% [40]. In addition, soil fertility can be improved by using a variety of fertilizer mixtures with different fertilization regimes [41]. Plant winter cover crops during fallow periods to improve soil fertility and reduce fertilizer application [42]. Rapeseed, as the first rotation crop, can improve soil fertility, thereby increasing rice yield and ultimately reducing nitrogen application [43].

Scholars have explored how to achieve fertilizer reduction at the technical and management levels respectively [25, 31, 36]. In terms of research content, the existing literature has given in-depth consideration to the causes, current situation and optimization paths of excessive fertilizer use, resulting in relatively rich theoretical research results that provide a reference for this study. With the gradual improvement of fertilizer reduction technology, exploring the factors influencing farmers’ fertilizer reduction behavior is the key to controlling fertilizer abuse from the source.

2.2. Research related to farmers’ agricultural production behavior

Farmers are the mainstay of China’s agricultural operations, and chemical fertilizer application reduction must consider the production
farmers' behavior. In terms of chemical fertilizer reduction behavior of farmers, based on an extended theory of planned behavior, Savari and Gharechaei (2020) used structural equation model with questionnaire data from 410 wheat farmers in Iran to explore the factors influencing fertilizer application by farmers. It was found that moral norms, risk perceptions, attitudes, perceived behavioral control and subjective norms have decreasing effect size on fertilizer application by farmers [44]. In terms of increasing organic fertilizer application behavior of farmers, Lu et al. (2019) analyzed the influence of land property rights stability on farmers' organic fertilizer application and its mechanism based on logit model and the 2017 China Rural Household Panel Survey from Zhejiang University. The study shows that land property rights stability is beneficial to farmers' organic fertilizer application [45]. Ma and Zheng (2022) explored the heterogeneous impact of information technology adoption on pesticide and fertilizer expenditure, finding that smartphone use significantly reduced fertilizer application by wheat farmers [46]. In terms of organic fertilizer replacing chemical fertilizer behavior of farmers, based on data from the Tobit model and a survey of Chinese apple farmers, Wang et al. (2018) found that membership in agricultural cooperatives, organic fertilizer subsidies, and farm size played an active role in influencing farmers' choice of organic fertilizers instead of chemical fertilizers [47]. Using the DID method and the survey data of 281 greenhouse vegetable farmers in China, Yi et al. (2021) found that the subsidy policy of organic fertilizer replacing chemical fertilizer had a positive effect on farmers' behavior [48]. Based on quasi-natural experimental data and DID method, Hu et al. (2021) explored the impact of land consolidation rights policy on fertilizer use by Chinese farmers. The results show that land consolidation rights motivate farmers to reduce fertilizer use by 63.52 yuan per mu and increase organic fertilizer use by 24.29 pounds per mu [49].

In terms of research methods, most scholars have conducted quantitative research using mathematical and econometric models supported by micro-regional research data [44, 45, 48]. However, the factors influencing farmers' chemical fertilizer use behavior may interact, so the use of traditional econometric models will inevitably lead to multicollinearity.

2.3. Research related to farmer differentiation

With the rapid urbanization in China, a large amount of agricultural land has been transformed into non-agricultural land, leading to the emergence of many landless farmers and farmer differentiation. As the proportion of off-farm income grows, farmers' dependence on agriculture gradually decreases. Participation in off-farm work had a positive and statistically significant impact on fertilizer and pesticide expenditure [50]. Xie (2019) compared the employment differentiation of landless farmers before and after land expropriation based on survey data in Nanjing. The study finds that about 54% of landless farmers have significant employment differentiation, such as migrant workers and unemployment [51]. Liu et al. (2020) analyzed the impacts of farmer differentiation on farmers' behaviors to withdraw from rural homesteads using the Probit model and 1909 survey data of farmers in China. The findings suggest that about 54% of landless farmers have significant employment differentiation, such as migrant workers and unemployment [51]. Liu et al. (2020) analyzed the impacts of farmer differentiation on farmers' behaviors to withdraw from rural homesteads using the Probit model and 1909 survey data of farmers in China. The findings suggest that about 54% of landless farmers have significant employment differentiation, such as migrant workers and unemployment [51].

3. Theoretical framework

3.1. Chemical fertilizer application reduction behavior of farmers

Chemical fertilizer application reduction behavior is the reduction of chemical fertilizer application by agricultural production and management subjects through the adoption of various technical means, on the premise of ensuring that crop yields are not reduced [55]. The way to achieve the reduction of chemical fertilizer application is mainly through the absolute decrease of the application quantity and the reasonable adjustment of the chemical fertilizer application structure [34]. When the purchase and use costs of chemical fertilizer increase and the unit income obtained by increasing the amount of chemical fertilizer use is lower than the purchase and use costs of chemical fertilizer, rational farmers will take the initiative to reduce the amount of chemical fertilizer application. On the other hand, the government can impose penalties on farmers who use excessive chemical fertilizer through environmental regulation to force them to reduce the amount of chemical fertilizer applied. However, this approach requires a lot of human and material resources to implement and is costly and not very feasible. The rational adjustment of chemical fertilizer application structure mainly includes two levels of connotation. On the one hand, reduce the amount of compound chemical fertilizer application through the adoption of soil testing and formulation technology to achieve the best chemical fertilizer application ratio with the minimum element demand that guarantees no reduction in yield. On the other hand, adopt new chemical fertilizers such as slow-release chemical fertilizers, green chemical fertilizers, and organic chemical fertilizers [30, 38], abandoning the traditional chemical fertilizers, thus achieving an overall decrease in the amounts of chemical fertilizers applied. (1) technology cognition and farmers' chemical fertilizer reduction behavior. Farmers' technology cognition can indirectly influence individuals' actions by regulating the strength of their behavioral intentions [56]. Differences in farmers' technology cognition of chemical fertilizer reduction application leads to differences in their chemical fertilizer reduction behaviors. Positive technology cognition will increase the likelihood of chemical fertilizer reduction technology adoption and make farmers adopt chemical fertilizer reduction behaviors, and conversely, make farmers refuse to adopt chemical fertilizer reduction behaviors. Based on this, this study proposes the following hypothesis.

H1. There is a positive effect of farmers' technology cognition on farmers' chemical fertilizer reduction behavior.

(2) Farmer characteristics and farmers' chemical fertilizer reduction behavior. Farmer characteristics include the household head's personal characteristics and the resource endowment's characteristics. Personal characteristics such as gender and age can influence farmers' adoption of technologies [57, 58]. Specifically, older farmers have more knowledge and field experience and are relatively well informed about fertilizer reduction technologies [59]. Compared to women, male farmers have a higher level of technology cognition and show a positive attitude towards the diffusion of new technologies. Better educated farmers tend to have higher social capital and are able to accept the risk of replacing traditional technologies with new ones. Farmers'
resource endowment refers to the factors of production owned (or at the disposal and use) by farming households. It has a direct impact on farming decisions in production and management. The impact of farmer characteristics on farmers’ behavior towards fertilizer reduction is mainly reflected in two aspects: firstly, it enhances farmers’ technological awareness and increases their willingness to reduce fertilizer application. Secondly, it enhances farmers’ social capital and raises their expectations of fertilizer reduction. Specifically, the larger the area of arable land operated by a farmer, the higher the cost of farming materials. Therefore, the more likely it is that farmers will adopt reduced fertilizer application techniques. The greater the fragmentation of plots, the more often machinery enters the land and the more cumbersome the labor procedures, the more farmers are inclined to reduce fertilizer application. Arable land with fertile soils tends to be more productive, less dependent on chemical fertilizers. Therefore, farmers with fertile arable land are more inclined to reduce fertilizer application. Farmers with sizeable agricultural machinery (seeders, harvesters) are more inclined to adopt labor-saving techniques and have a tendency to reduce fertilizer. Based on this, this study proposes the following hypothesis.

**H2.** Farmer characteristics have a positive effect on farmers’ reducing chemical fertilizer application behavior.

**H3.** Farmer characteristics positively affect farmers’ technology cognition.

**H4.** Farmer characteristics have a positive effect on farmers’ social capital.

(3) Social capital and farmers’ chemical fertilizer reduction behavior. Social capital mainly refers to the interpersonal relationships and forms of cooperation that individuals have in social groups or social networks, a kind of invisible capital that can exert capital benefits. It is specifically expressed as the influence of the policy, institutional and social environment atmosphere in which farmers are located on their fertilization behavior [44]. As a member of rural society, farmers are influenced by influential individuals or groups around them before adopting chemical fertilizer reduction [47]. The influence of different influential individuals or groups on farmers’ chemical fertilizer reduction behavior varies greatly. Based on this, this study proposes the following hypothesis.

**H5.** Farmers’ social capital has a significant positive effect on farmers’ chemical fertilizer reduction behavior.

### 3.2. The impact of farmer differentiation on chemical fertilizer reduction behavior

Farmer differentiation mainly influences farmer characteristics, technology cognition and social capital, which in turn influence fertilizer reduction behavior.

(1) Farmer differentiation and farmer characteristics. In the context of farmer differentiation, different types of farmers have different sources of livelihoods. Among them, small-scale pure farmers and large professional farmers have a single source of livelihood and are more dependent on agriculture, considering chemical fertilizer as an important agricultural material. However, small-scale farmers cultivate on a smaller scale, and the impact of fertilizer reduction on their production costs is not obvious. With the increase of fertilizer prices, the cost-saving effect of fertilizer reduction for large professional households becomes more and more significant, and they are more inclined to reduce fertilizer application. In contrast, part-time farmers have multiple sources of livelihood and are less dependent on agriculture [50]. Fertilizer reduction requires an investment of time and energy. Therefore, as off-farm labor time and off-farm income increase, part-time farmers are more likely to follow traditional fertilizer application methods.

(2) Farmer differentiation and technology cognition. With the development of urbanization, farmers engaged in agricultural activities in rural areas of China show an aging trend. Constrained by age and education, small-scale farmers have a low level of awareness of fertilizer reduction technologies. In order to obtain more income, part-time farmers focus more on off-farm business activities and have a lower level of awareness of fertilizer reduction technologies. Large professional farmers put more attention on agricultural activities and are able to obtain timely information on advanced agricultural production technologies. Therefore, they will learn about the benefits of fertilizer reduction through various sources and possess a higher level of technical awareness.

(3) Farmer differentiation and social capital. In recent years, China has encouraged moderate scale agricultural operations and actively guided large professional farmers to participate in agricultural associations or cooperatives. Large professional farmers tend to actively receive agricultural technology training, actively exchange agricultural production techniques with others, and have high social capital. Although small-scale pure farmers also frequently communicate with each other [44], their knowledge of fertilizer reduction techniques is generally low. Part-time households lacked the motivation to join agricultural associations or cooperatives and rarely exchanged agricultural production techniques with others. Moreover, they may go out to work and generally do not serve as village leaders, and their social capital is low.

Based on the above analysis, this paper constructs a theoretical analysis framework of farmers’ chemical fertilizer reduction under the perspective of farmer differentiation, as shown in Figure 1.

### 4. Study design

#### 4.1. Data

The data of this paper are obtained from the questionnaire survey of farmers by the research team. The research team was mainly composed of teachers, masters’ and doctoral students in agricultural economic management, with a total of 10 members. Since 2020, Qingdao city has been implementing the concept of green agricultural development and adjusting the structure of chemical fertilizer inputs. By reducing traditional chemical fertilizers and increasing the use of organic fertilizers, Qingdao has achieved significant results in reducing fertilizers and increasing their efficiency and comprehensive management. Therefore, Qingdao was chosen as a representative sample region for the survey.

Considering that farmers’ fertilizer behavior changes rapidly, this paper uses a sample survey to investigate farmers’ fertilizer reduction behavior in Qingdao. The sampling survey method collects and collates data quickly, ensures the timeliness of the survey, dramatically reduces survey costs and improves survey efficiency. Based on the principle of systematic sampling and taking into account the development of rural...
society in Qingdao, we selected 35 representative villages as sample areas. The details are shown in Table 1. The research team conducted seven research activities and distributed 900 questionnaires. 889 valid questionnaires were recovered after excluding incomplete questionnaires, invalid questionnaires with extreme answers, and invalid questionnaires with all the same answers.

Based on the theory of farmer differentiation, referring to the research of Xie and Jin [16] (2019), Stringer et al. [60] (2020), this paper has classified farmers into categories according to 3 indicators: cultivation area, the share of off-farm income and off-farm labor time. The specific classification results are shown in Table 2. In recent years Qingdao city presents the reality that large professional households and part-time households are the main types of farming households, and many types of farming households coexist. Among them, small-scale pure farmers accounted for a low proportion of the sample, only 9.63%, indicating that most small-scale farmers are detached from agricultural production and have diversified their sources of livelihood. Part-time farmers account for 59.71% of the survey sample, which indicates that a significant proportion of farmers are engaged in agricultural production and also obtain economic income through other off-farm business methods. Large professional farmer account for a higher proportion, 30.66%. They have become the main body of grain production in Qingdao, which may be related to the fact that Qingdao actively guides farmers to operate on a large scale through land transfer. Large professional farmers have a large scale of agricultural cultivation and are able to increase their farming income through the scale effect.

4.2. Variables

According to the theoretical model, the dependent variable of this paper is farmers’ chemical fertilizer reduction behavior and the main independent variables are farmer characteristics, social capital and technical cognition.

4.2.1. Farmer characteristics

4.2.1.1. Individual characteristics. According to the previous theoretical analysis, farmer characteristics can be subdivided into the personal characteristics of the household head and the farmer’ resource endowment characteristics. The household head usually plays a central role in household production and decisions. The gender, age, and education of the household head influenced the farmers’ attitudes toward fertilizer reduction, and the years of farming experience influenced the farmers’ reliance on traditional farming experience. Fertilizer reduction needs to invest more time and energy, such as: replacing traditional fertilizer with new fertilizer, improving the resource utilization of livestock and poultry waste, etc. Therefore, farmers with poor physical health may be resistant to it. Accordingly, the individual characteristics of household heads were measured by five aspects: gender, age, education, years of farming experience and health status.

4.2.1.2. Resource endowment. Resource endowments are production factors that are owned (or can be disposed of) by farmers and have a direct impact on farm decisions. With the expansion of farmers’ cultivated land, the cost-saving benefit of chemical fertilizer reduction is obvious, and thus the higher the chemical fertilizer reduction behavior. The higher the degree of fragmentation of cultivated land and the more tedious the labor procedure, the weaker the farmers’ chemical fertilizer reduction behavior. Arable land with rich soil properties tends to have higher productivity and less dependence on fertilizers. Therefore, farmers with fertile farmland are less willing to adopt fertilizer reduction techniques. Farmers with sizeable agricultural machinery (planters, harvesters) are more inclined to adopt labor-saving technology, and are not interested in labor-consuming and time-consuming reduced-fertilization technology. Accordingly, the household resource endowment was mainly characterized by 4 aspects: the degree of fine fragmentation of cultivated land, management area, soil fertility, and mechanization.

4.2.2. Technical cognition

Technology awareness is the extent to which farmers know about the adoption methods and effects of fertilizer reduction technologies. The research team found that fertilizer prices have shown an increase in recent years, which to a certain extent has contributed to fertilizer reduction. Farmers are rational, therefore, operational effect cognition and income-increasing cognition will directly affect whether they reduce fertilizer application. To achieve chemical fertilizer reduction, it is necessary to improve the fertilizer application method, adjust the structure of chemical fertilizer use, and use organic fertilizer to replace part of the chemical fertilizer, which is more tedious than the traditional diffuse application method. Therefore, farmers’ cognition of convenience and time-saving are important factors influencing their fertilizer reduction behavior. Accordingly, the technology cognition is characterized by four indicators: operational effect cognition, convenience cognition, time-saving cognition, and income-increasing cognition.

4.2.3. Social capital

In rural areas of China, farmers have naturally formed their own social networks with the function of disseminating information over a long period of time. First, farmers who have family members working as village cadres or agricultural technicians tend to have better information about fertilizer reduction technologies, are more inclined to reduce fertilizer application, and play the role of technology disseminators in their social networks. Second, communication between farmers and their neighbors and friends can facilitate the dissemination of fertilizer reduction technologies and reduce farmers’ perception of the risks of fertilizer reduction technologies. Third, agricultural associations and cooperatives are important intermediary organizations for promoting fertilizer reduction technologies. Farmers who join agricultural associations or cooperatives have more opportunities to understand the advantages of fertilizer reduction technologies through technical communication and other means, and are more inclined to reduce fertilizer application. Fourth, farmers’ production decisions may also be influenced by other farmers. With the increased promotion of green production technologies, farmers who communicate frequently with their neighbors or friends tend to have a higher degree of knowledge about new technologies and are more inclined to adopt them. Accordingly, social capital was characterized in four main aspects: appointment, frequency of communication, association activities, and influence of others.

| Table 1. Distribution of the survey sample. |
|-------------------------------------------|
| Region               | Number of villages in the sample | Number of questionnaires distributed (copies) | Number of questionnaires returned (copies) |
|----------------------|----------------------------------|-----------------------------------------------|--------------------------------------------|
| Jimo District        | 8                                | 200                                           | 198                                        |
| Jiaozhou City        | 9                                | 200                                           | 197                                        |
| Pingdu City          | 11                               | 300                                           | 296                                        |
| LaiXi City           | 7                                | 200                                           | 198                                        |

| Table 2. Classification of farmer typesunit % |
|-----------------------------------------------|
| Farmers type            | Farm size/ total size | Share of off-farm labor time | Share of off-farm income | Sample ratio |
|-------------------------|----------------------|-------------------------------|--------------------------|--------------|
| Small-scale pure farmer | 1–20                 | 0–20                          | 0–10                     | 9.63         |
| Part-time farmer        | 20–80                | 20–80                         | 20–80                    | 59.71        |
| Large professional farmer | 80–100              | 0–20                          | 0–10                     | 30.66        |
The definitions and assignments of variables are shown in Table 3.

### 4.3. Model

Since farmer characteristics, technology cognition, social capital, and chemical fertilizer application behavior are latent variables, using ordinary OLS regressions would result in too large an error. This study used the Structural Equation Model (SEM) to empirically test farmers’ chemical fertilizer reduction behavior. Structural Equation Model not only constructs non-observed latent variables, but also estimates the relationship between latent variables that are not affected by measurement error, which fits the needs of this study. The measurement equations and structural equations for farmers’ chemical fertilizer reduction behavior are shown below.

\[ \eta = B \eta + \Gamma \xi + \tau \]  
\[ X = A \xi + \delta \]  
\[ Y = A \eta + \epsilon \]  

| Table 3. Variable definitions. |
|-------------------------------|
| **Variable** | **Variable definition** |
| Application | behavior | Willing | Farmers’ chemical fertilizer reduction application as a whole, with 1 not willing, 2 somewhat willing, 3 willing, and 4 very willing. |
| Behavior | Farmers’ chemical fertilizer reduction behavior, with 1 indicating a low degree, 2 indicating a relatively low degree, 3 indicating a relatively high degree, 4 indicating a high degree, and 5 indicating a very high degree. |
| Farmer | characteristics | Gender | Gender of head of household, with 0 indicating male and 1 indicating female. |
| | | Age | Actual age as of December 2019. |
| | | Education | Below elementary school = 1, elementary school = 2, junior high school = 3, junior college or above high school = 4, above high school = 5. |
| | | Years | Years of farming for the head of the household (years). |
| | | Health | Physical health of the head of household, with 0 indicating unhealthy, 1 indicating relatively healthy, 2 indicating healthy, 3 indicating very healthy, and 4 indicating extremely healthy. |
| | | Fragmentation | Total number of land parcels operated (blocks). |
| | | Area | Total number of acres of land operated (mu). |
| | | Fertility | Fertility of the soil, with 0 indicating poor, 1 indicating fair, 2 indicating good, 3 indicating very good, and 4 indicating extremely good. |
| | | Machinery | Whether to have large agricultural machinery, with 0 indicating no and 1 indicating yes. |
| Social | capital | Appointment | Whether family member is a village cadre or agricultural technician, with 0 indicating no and 1 indicating yes. |
| | | Frequency | Do you exchange agricultural production techniques with others, with 0 indicating no and 1 indicating yes. |
| | | Association | Are you involved in an agricultural association or cooperative, with 0 indicating no and 1 indicating yes. |
| | | Influence | Whether your friends’ business behavior has an impact on you, with 0 indicating no and 1 indicating yes. |
| Technical | cognition | Convenience | Whether reduced chemical fertilizer application enhances convenience, with 1 indicating not convenient, 2 indicating somewhat convenient, 3 indicating relatively convenient, and 4 indicating convenient. |
| | | Effect | How effective is the operation of chemical fertilizer reduction application, with 1 indicating very bad, 2 indicating bad, 3 indicating not good, 4 indicating relatively good, and 5 indicating good. |
| | | Time | Chemical fertilizer reduction technology can effectively save farming time, with 1 indicating very fast, 2 indicating fast, 3 indicating relatively fast, 4 indicating fast, and 5 indicating slow. |
| | | Income | Chemical fertilizer reduction techniques can increase farm income, with 1 indicating very bad, 2 indicating bad, 3 indicating not very willing, 4 indicating willing, and 5 indicating very willing. |

In the structural Eq. (1), \( B \eta \) describes the influence of endogenous variables \( \eta \) on each other; \( \Gamma \xi \) describes the influence of exogenous latent variables \( \xi \) on endogenous latent variables \( \eta \); and \( \tau \) denotes the residual term. In the measurement equation, Eq. (2) represents the measurement equation of the exogenous latent variable and Eq. (3) represents the measurement equation of the endogenous latent variable.

### 5. Results and discussion

#### 5.1. Questionnaire reliability and validity analysis

##### 5.1.1. Reliability analysis

Reliability analysis can test the stability and internal consistency of a questionnaire. In this paper, we use Cronbach’s Alpha coefficient, a commonly used reliability test, which identifies whether the observed variables of the scale can measure the same concept and whether different items have similar characteristics. In this paper, SPSS22.0 software was used to analyze the reliability of the research data, and the results of the overall reliability analysis of the scale are shown in Table 4. The overall Cronbach’s Alpha coefficient for the 19 observed variables in the scale was 0.887, indicating that there was high internal consistency among the items in the chemical fertilizer reduction behavior scale. The overall reliability of the questionnaire could not be improved even if any of the items were deleted.

##### 5.1.2. Validity analysis

Questionnaire validity is the degree to which a questionnaire can accurately measure the thing to be measured. To test whether the correspondence between the study factors and the questionnaire measures is as expected, this paper used Confirmatory Factor Analysis (CFA) to measure the potential structure that was developed. First, using SPSS 22.0 software, we conduct a Kaiser-Meyer-Olkin (KMO) test and Bartlett’s test on the questionnaire to determine whether the sample data could be subjected to validated factor analysis. The analysis results are shown in Table 5. As shown by the KMO and Bartlett’s test results, the KMO value is more than 0.8 and Bartlett’s sphere test is significant at the 1% level, which indicate that the sample data have a strong correlation and are well suited for factor analysis.

Principal component analysis, principal axis factor method, and great likelihood method are commonly used factor extraction methods. Compared with other factor extraction methods, principal component analysis can achieve the reduction of multiple variables based on linear equations. The variables are classified and combined by extracting common features and common explained variances. The linear combination after classification and combination is the principal component. In this paper, the maximum variance method of principal component analysis is used to pivot, taking 1 as the boundary eigenvalue and 0.5 as the factor loading, and deleting factor loading coefficients below 0.5 as well as measurement terms more than 0.5 on multiple factors. The results of the validated factor analysis for each measured variable are shown in Table 6, from which it can be seen that the Cronbach’s Alpha coefficient of each factor is more than 0.7, which has high reliability. The variance contribution of each factor is high, with a cumulative variance contribution of more than 80%, which can explain the consistency among variables to a large extent.

#### 5.2. Model estimation results and analysis

Based on the validation factor analysis of each latent variable, this paper uses AMOS software to conduct the basic fit criterion test and the
overall model fit criterion test on the theoretical model of farmers’ fertilizer reduction behavior, and further investigates the influence paths of various factors on fertilizer reduction behavior. The test results show that the measurement errors of all indicators are positive, and the factor loadings of the measurement questions for all four latent variables are between 0.5 and 0.95, which meet the basic fit test criteria. χ² with a degree of freedom ratio less than 2 indicates that the model fits well overall. In this paper, the NFI, IFI, TLI and CFI index are all more than 0.9, and the RMSEA is less than 0.05, indicating that the overall model fit is good.

The results of Structural Equation Model estimation are shown in Table 7, which shows that the path coefficients of each latent variable are 0.089, 0.116, 0.185, 0.428 and 0.314, respectively. The test coefficients of hypotheses H1, H2, H3, H4, and H5, P value are all less than 0.001 and pass the significance test. That is, the above five hypotheses cannot be rejected.

1. The path coefficient of technology cognition on chemical fertilizer reduction application behavior is 0.089 and significant at the 1% level, indicating that farmers' technology cognition positively affects chemical fertilizer reduction behavior. The more farmers know about the characteristics, applicability and advantages of chemical fertilizer reduction technology, the more inclined they farmers are to adopt this technology.

2. The path coefficient of farmer characteristics' effect on chemical fertilizer reduction behavior is 0.126, which is significant at the 1% level, indicating that farmer characteristics positively influenced chemical fertilizer reduction behavior. The path coefficient of farmer characteristics on technology cognition is 0.185 and significant at the 5% level, indicating that the farmer characteristics positively affect farmers' technology cognition. The path coefficient of farmer characteristics on social capital is 0.428 and significant at the 1% level, indicating that the farmer characteristics had a positive effect on the farmer's social capital. It can be seen that farmer characteristics can not only directly influence farmers’ fertilizer reduction behavior, but also influence farmers' fertilizer reduction behavior by influencing 2 mediating variables: technology perception and social capital.

3. The path coefficient of social capital on chemical fertilizer reduction behavior is 0.314. It is significant at the 1% level, indicating that farmers' social capital positively affects chemical fertilizer reduction behavior. Communication among farmers not only enhances farmers’ awareness of fertilizer reduction, but also allows farmers to imitate and learn from each other, further subtly promoting fertilizer reduction technology. Among the three core variables, social capital had the highest degree of influence on farmers’ chemical fertilizer reduction behavior, followed by farmer characteristics, and the lowest is technology cognition.

5.3. Influence of farmer fragmentation on chemical fertilizer reduction behavior

To further test the effect of farmer differentiation on farmers' chemical fertilizer reduction behavior, the samples are divided into three groups according to the farmers' types. We analyzed three sub-sample models, and the results are shown in Table 8.

1. Small-scale pure farmer model. The path coefficient of technology cognition's effect on small-scale pure farmers' chemical fertilizer reduction behavior is 0.089, but it is not significant. Most of the small-scale pure farmers are subsistence farmers and do not have a strong demand for chemical fertilizer reduction technology, so their technology cognition are generally in a low level, which might be limited by their education level. The path coefficient of farmer characteristics' effect on small-scale pure farmers' chemical fertilizer reduction behavior is 0.113, which is significant at the 5% level. The coefficient of farmer characteristics' effect on social capital is 0.317, which is not significant, indicating that small-scale pure farmers have weaker resource endowment and are in a weaker position both in technology exchange, serving in the village, and cooperative participation. The path coefficient social capital's effect on the chemical fertilizer reduction behavior of small-scale pure farmers is 0.141, which is significant at the 10% level.

2. Part-time farmer model. The path coefficient of technology cognition on part-time farmers’ chemical fertilizer reduction behavior is 0.097, which is significant at the 1% level. The path coefficient of farmer characteristics' effect on chemical fertilizer reduction behavior of part-time farmers is 0.263, which is not significant. For part-time farmers, the income from agricultural business is only a small part of the household income, and their main focus is on non-agricultural activities. Therefore, none of them are interested in chemical fertilizer reduction application technology. The coefficient of farmer characteristics' effect on technology cognition is 0.141, which is significant at the 5% level.
The coefficient of farmer characteristics’ effect on social capital is 0.407, which is not significant. The main working time and energy of part-time farmers are in urban work, and thus their social capital is also in urban life, which lead to a disconnection between social capital and agricultural operations. The path coefficient of social capital’s effect on part-time farmers’ chemical fertilizer reduction behavior is 0.293, which is significant at the 10% level.

(3) Professional large farmer model. The path coefficient of technology cognition on chemical fertilizer application reduction behavior of large professional farmers is 0.189, which is significant at the 1% level. The large professional farmers in rural areas are highly educated and have a higher degree of knowledge of chemical fertilizer reduction technology. The path coefficient of farmer characteristics on large professional farmer’s chemical fertilizer reduction behavior is 0.173, which is significant at the 1% level. The larger the cultivated land of large professional farmer and the higher the resource endowment, the more obvious the scale effect of reduced fertilizer application. Therefore, the larger the scale of farmers’ cultivated land, the more inclined they are to reduce fertilizer application. The coefficient of farmer characteristics’ effect on technology cognition is 0.216, which is significant at the 1% level. The larger the scale of cultivation, the higher the demand for agricultural technology. Driven by the demand, large professional households exhaust their efforts to learn new knowledge and master new technology, and this is no exception for chemical fertilizer reduction application technology, which can save costs, improve product quality, and achieve sustainable development of farmland. The coefficient of farmer characteristics’ effect on social capital is 0.327, which is not significant. The path coefficient of social capital’s effect on large professional farmer’s chemical fertilizer reduction behavior is 0.251, which is significant at the 1% level. Large professional farmers generally hold positions in villages or are leaders of farmers’ cooperatives, who are more well-connected and more willing to accept chemical fertilizer reduction technologies.

5.4. Discussion

The main issue of this paper is the factors influencing farmers’ fertilizer reduction application and the impact of farmer differentiation on fertilizer application reduction behavior. The results show that technology cognition, business characteristics, and social capital significantly and positively influence farmers’ fertilizer reduction behavior. From the perspective of farmer differentiation, technology cognition, business characteristics and social capital have different effects on fertilizer application reduction behavior of different types of farmers. The research questions in this paper are answered.

First, in terms of social capital that influences farmers to reduce fertilizer application, Savari and Gharnechaee (2020) found that moral norms, perceived behavioral control, and subjective norms have decreasing effect on farmers’ fertilizer application [44]. On the contrary, the result of this paper is that social capital can promote farmers to reduce fertilizer consumption. Second, in terms of technology cognitions that influence farmers’ fertilizer reduction application, Ma and Zheng (2022) found that information technology adoption, such as smartphone use, significantly reduced farmers’ fertilizer application [46]. The findings of this paper are similar. Third, in terms of the business characteristics that influence farmers’ fertilizer reduction application, Wang et al. (2018) found that membership in agricultural cooperatives and farm size played an active role in influencing farmers’ choice of organic fertilizers instead of chemical fertilizers [47]. The findings of this paper are the same. Fourth, in terms of the impact of farm household differentiation, Li and Sheng (2021) found that large-scale farmers do not often apply organic fertilizers [53]. The results of this paper differ, which found that large professional farmers are more willing to reduce fertilizer application in order to save time and effort in farming.

However, there are deficiencies in this paper. First, farmers’ fertilizer application reduction is influenced by many factors, and this paper considers technology cognition, business characteristics and social capital from the perspective of farmers. Other influencing factors can be further explored in the future in terms of policy and environment. Second, the fertilizer application habits of farmers may change over time. This paper uses cross-sectional data, which cannot analyze the dynamic changes of farmers’ fertilizer application behaviors, and panel data can be obtained to deepen analysis in the future.

6. Conclusions and recommendations

6.1. Conclusions

The total chemical fertilizer application in China remains high and far exceeds the international average, leading to severe surface pollution. In this paper, after a questionnaire survey on 889 farmers’ chemical fertilizer application behavior, we analyze farmers’ chemical fertilizer reduction behavior and its influencing factors at the theoretical and empirical levels. Further, we analyze the influence of farmers’ differentiation on farmers’ chemical fertilizer reduction behavior. The following research conclusions are obtained.

First, farmer characteristics, technology cognition and social capital all significantly and positively influence farmers’ chemical fertilizer reduction behavior. Among them, social capital has the highest degree of influence on farmers’ chemical fertilizer reduction behavior, followed by farmer characteristics, and the technology cognition has the lowest degree of influence.

Second, the effect of technology cognition on chemical fertilizer reduction behavior of small-scale pure farmers is not significant, but the effect on chemical fertilizer reduction behavior of part-time farmers and large professional farmers is significant, and the effect on large professional farmers is higher.

Fourth, the effect of social capital on the chemical fertilizer reduction behavior of small-scale pure farmers, part-time farmers, and large
6.2. Recommendations

First, improve the policy support for chemical fertilizer reduction and application. The government should set a reasonable subsidy range for organic chemical fertilizer application, actively guide farmers to implement a variety of chemical fertilizers mixed use of fertilizer, and grasp the timing of fertilization to achieve the complementary effect of chemical fertilizers and farm chemical fertilizers. At the same time, continue to promote the straw return technology, through the straw left in the ground and other ways so that the straw can be broken down into nutrients beneficial to crop growth, thereby reducing the amount of chemical fertilizer application.

Second, enhance the chemical fertilizer reduction application technology support. Local agricultural departments should set up a dedicated team for soil measurement and formula fertilization technology promotion to accelerate the promotion of soil testing formula and precise chemical fertilizer technology. Actively guide the development and innovation of satellite positioning, remote sensing and other technologies, innovate the means of information acquisition, fully use information technology to enhance the accuracy of soil testing, improve the speed of testing, and effectively guarantee the effectiveness of soil formula fertilization technology implementation.

Third, enhance the education guidance on chemical fertilizer reduction and application. Make efforts to increase farmers’ vocational education and improve the education platform for the whole period of time, so as to enhance farmers’ awareness of chemical fertilizer reduction techniques. In addition to propaganda and promotion, local agricultural departments should also strengthen field teaching and encourage agricultural extension staff to teach farmers on the spot to gradually raise farmer’s awareness of modern chemical fertilizer application techniques.

Fourth, promote fertilizer reduction based on the characteristics of different types of farmers. With the evolution of farmer differentiation, different types of farmers have different degrees of dependence on agriculture, and their chemical fertilizer reduction and application behaviors also differ. Therefore, local agricultural departments should fully combine the characteristics of different types of farmers and develop targeted publicity paths for chemical fertilizer reduction, build a feedback platform for farmers' demand for chemical fertilizer reduction and application. In addition, innovate the promotion mechanism for chemical fertilizer reduction and application, focus on the chemical fertilizer reduction and application behaviors of various types of farmers, and pay particular attention to large groups of farmers with large-scale arable land.

Declarations

Author contribution statement

Shan Zheng: Conceived and designed the experiments; Wrote the paper.
Keqing Yin: Performed the experiments; Analyzed and interpreted the data.
Lianghong Yu: Contributed reagents, materials, analysis tools.

Funding statement

This work was supported by the National Natural Science Foundation of China[grant number 71901199, 72273135].

Data availability statement

Data will be made available on request.

Declaration of interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

[1] H. Takeshima, R.P. Adhikari, S. Shivakoti, B.D. Kaphle, A. Kumar, Heterogeneous returns to chemical fertilizer at the intensive margins: insights from Nepal, Food Pol. 69 (2017) 97–109.
[2] S.M.M. Islam, Y.K. Gaihre, Md.R. Islam, Md.N. Ahmed, M. Akter, U. Singh, B.O. Sander, Mitigating greenhouse gas emissions from irrigated rice cultivation through improved fertilizer and water management, J. Environ. Manag. 307 (2022), 114335.
[3] B. Moya, A. Parker, R. Sakrabani, Challenges to the use of fertilizers derived from human excreta: the case of vegetable exports from Kenya to Europe and influence of certification systems, Food Pol. 85 (2019) 72–78.
[4] M. Mencaroni, N. Dal Ferro, J. Furlanetto, M. Longo, B. Lazzaro, L. Sartori, B.B. Grant, W.N. Smith, F. Morari, Identifying N fertilizer management strategies to reduce ammonia volatilization: towards a site-specific approach, J. Environ. Manag. 277 (2021), 114445.
[5] H. Ayalew, J. Chamberlin, C. Newman, Site-specific agronomic information and technology adoption: a field experiment from Ethiopia, J. Dev. Econ. 156 (2022) 102788.
[6] A.B. Cecilio Filho, C.S. Nascimento, B. de J. Pereira, C.S. Nascimento, Nitrogen fertilizer impacts greenhouse gas emissions, carbon footprint, and agronomic responses of beet intercropped with arugula, J. Environ. Manag. 307 (2022), 114568.
[7] A.P. Harou, M. Madajewicz, H. Michelson, C.A. Palm, N. Amuri, C. Magomba, J.M. Semoka, K. Tischler, R. Weil, The joint effects of information and financing constraints on technology adoption: evidence from a field experiment in rural Tanzania, J. Dev. Econ. 155 (2022) 102797.
[8] J. Blomquist, M. Nordin, Do the CAP subsidies increase employment in Sweden? estimating the effects of government transfers using an exogenous change in the CAP, Reg. Sci. Urban Econ. 63 (2017) 13–24.
[9] T. Berger, C. Troost, T. Wessen, E. Latyskiy, K. Tesfaye, S. Gbengebele, Can smallholder farmers adapt to climate variability, and how effective are policy interventions? Agent-based simulation results for Ethiopia, Agric. Econ. 48 (2017) 693–706.
[10] R.D. Bollman, S.M. Ferguson, The local impacts of agricultural subsidies: evidence from the Canadian prairies, J. Agric. Econ. 70 (2019) 507–528.
[11] P.S. Ward, S. Gupta, V. Singh, D.L. Ortega, S. Gautam, What is the intrinsic value of fertilizer? Experimental value elicitation and decomposition in the hill and terai regions of Nepal, Food Pol. 90 (2020), 101809.
[12] S. Zheng, L. Yu, The government’s subsidy strategy of carbon-sink fishery based on evolutionary game, Energy 254 (2022), 124282.
[13] V. Theriault, M. Smale, The unintended consequences of the fertilizer subsidy program on crop diversity in Mali, Food Pol. 102 (2021), 102121.
[14] N. Akber, K.R. Paltasingh, A.K. Mishra, How can public policy encourage private investments in Indian agriculture? Input subsidies vs. public investment, Food Pol. 107 (2022), 102210.
[15] W.J. Burke, T.S. Jayne, S.S. Snapp, Nitrogen efficiency by soil quality and management regimes on Malawi farms: can fertilizer use remain profitable? World Dev. 152 (2022), 105792.
[16] H. Xie, S. Jin, Evolutionary game analysis of fellow farmland behaviors of different types of farmers and local governments, Land Use Pol. 88 (2019), 104122.
[17] N.M. Mason, T.S. Jayne, Fertilizer subsidies and smallholder commercial fertilizer purchases: crowding out, leakage and policy implications for Zambia, J. Agric. Econ. 64 (2013) 558–582.
[18] S. Kajiyata, J. Ricker-Gilbert, C. Jumbe, What does Malawi’s fertilizer programme do to private sector fertilizer sales? A quasi-experimental field study, J. Agric. Econ. 70 (2019) 332–352.
[19] W.M. Brown, S.M. Ferguson, C. Viju-Milusie, Farm size, technology adoption and agricultural trade reform: evidence from Canada, J. Agric. Econ. 71 (2020) 675–697.
[20] N. Zanisuddin, M.F. Keni, S.A.S. Ibrahim, M.M.M. Maari, Effect of integrated biofertilizers with chemical fertilizers on the oil palm growth and soil microbial diversity, Biocatal. Agric. Biotechnol. 39 (2022), 102327.
[21] N. Cai, M. Cai, X. Zhang, A.A. Abdelhafes, L. Zhou, H. Sun, G. Chen, G. Zou, S. Zhou, Runoff loss of nitrogen and phosphorus from a rice paddy field in the east of China: effects of long-term chemical N fertilizer and organic manure applications, Global Ecol. Conserv. 22 (2020), e0111.
[22] K. Bora, Spatial patterns of fertilizer use and imbalances: evidence from rice cultivation in India, Environ. Challenges 7 (2022), 100452.
[23] F. Li, J. Jin, S. He, J. Jin, Z. Wang, S. Khan, G. Tian, X. Liang, Use of polyacrylamide modified biochar coupled with organic and chemical fertilizers for reducing phosphorus loss under different cropping systems, Agric. Ecosyst. Environ. 310 (2021), 107306.
[24] E. Sinha, R. v Calvin, P.G. Kyle, M.I. Hejazi, S.T. Waldhoff, M. Huang, S. Vishwakarma, X. Zhang, Implication of imposing fertilizer limitations on energy, agriculture, and land systems, J. Environ. Manag. 305 (2022), 114391.
[25] J. Ren, X. Liu, W. Yang, X. Yang, W. Li, Q. Xia, J. Li, Z. Gao, Z. Yang, Rhizosphere soil properties, microbial community, and enzyme activities: short-term responses to partial substitution of chemical fertilizer with organic manure, J. Environ. Manag. 299 (2021), 113650.

[26] J. Fachini, C.C. de Figueiredo, A.T. do Vale, Assessing potassium release in natural silica sand from novel k-enriched sewage sludge biochar fertilizers, J. Environ. Manag. 314 (2022), 115086.

[27] N. Cao, J. Wang, J. Pang, W. Hu, H. Bai, Z. Zhou, Y. Meng, Y. Wang, Straw retention and improving crop yield in coastal saline soils, Field Crop. Res. 274 (2021) 108509.

[28] R.E. Carver, N.O. Nelson, K.L. Roozeboom, G.J. Kluitenberg, P.J. Tomlinson, J. Ren, X. Liu, W. Yang, X. Yang, W. Li, Q. Xia, J. Li, Z. Gao, Z. Yang, Rhizosphere soil properties, microbial community, and enzyme activities: short-term responses to partial substitution of chemical fertilizer with organic manure, J. Environ. Manag. 299 (2021), 113650.

[29] X. Yi, L. Yu, S.-H.-E. Chang, C. Yin, H. Wang, Z. Zhang, The effects of China’s Organic-Substitute-Chemical-Fertilizer (OSCF) policy on greenhouse vegetable farmers, J. Clean. Prod. 297 (2021), 126677.

[30] W. Ma, A. Abdulai, C. Ma, The effects of off-farm work on fertilizer and pesticide expenditures in China, Rev. Dev. Econ. 22 (2018) 573–591.

[31] Y. Xie, Land expropriation, shock to employment, and employment differentiation: findings from land-lost farmers in Nanjing, China, Land Use Pol. 87 (2019), 104040.

[32] R. Liu, C. Yu, J. Jiang, Z. Huang, Y. Jiang, Farmer differentiation, generational differences and farmers’ behaviors to withdraw from rural homesteads: evidence from Chengdu, China, Habitat Int. 103 (2020), 102231.

[33] A.A. Naghdli, S. Piri, A. Khaligi, P. Moradi, Enhancing the qualitative and quantitative traits of potato by biological, organic, and chemical fertilizers, J. Saud. Soc. Agric. Sci. 21 (2022) 87–92.

[34] W. Zhou, Q. Ma, L. Wu, R. Hu, D.L. Jones, D.R. Chadwick, H. Bao, L. Chen, Effects of the reduction in chemical fertilizer, J. Environ. Manag. 314 (2022), 115086.

[35] J. Luo, X. Shi, The impact of collective and individual drip irrigation systems on fertilizer use intensity and land productivity: evidence from rural Xinjiang, China, Water Resour. Econ. 38 (2022), 100196.

[36] C.F.A. van Wesenbeeck, M.A. Keyzer, W.C.M. van Veen, H. Qiu, Can China meet its sustainable development pathways for different types of farmers, Environ. Sci. Pollut. Res. 217 (2022), 105287.

[37] J. Jarait, N.F. Meriggi, E. Bulte, A.M. Mobarak, Subsidies for technology adoption: evidence from a quasi-natural experiment in cashew farmers in Ghana, Agric. Econ. 50 (2019) 749–763.

[38] P. Yanakittkul, C. Aungvaravong, A model of farmers intentions towards organic farming: a case study on rice farming in Thailand, Heliyon 6 (2020), e03039.

[39] B.T. Anang, A. Zakariah, Socioeconomic drivers of insolvent technology and chemical fertilizer utilization among smallholder soybean farmers in the Tolon District of Ghana, Heliyon 7 (2021), e05934.

[40] L.C. Stringer, E.D.G. Fraser, D. Harris, C. Lyon, L. Pereira, C.F.M. Ward, E. Simelton, Adaptation and development pathways for different types of farmers, Environ. Sci. Pol. 104 (2020) 174–189.