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Agricultural socialized services to stimulate the green production behavior of smallholder farmers: the case of fertilization of rice production in south China

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Introduction: This study investigates the impact of Agricultural Socialized Services (ASSs) on the green production behavior (GPB) of smallholder farmers in the main rice production region of southern China. The research aims to address the gap in understanding the relationship between ASSs and the adoption of sustainable agricultural practices by smallholder farmers.

Methodology: Data was collected from 741 smallholder farmers in Hunan, Jiangxi, and Zhejiang provinces using a structured questionnaire. A probit model was employed to examine the relationship between ASSs and smallholder farmers' GPB.

Results and Discussion: The study revealed that ASSs have a significant and positive impact on smallholder farmers' GPB. Farmers who received ASSs tended to adopt more sustainable agricultural practices such as using organic fertilizer and soil-tested formula fertilizer. The findings of this study have important implications for policymakers. The results suggest that policymakers should prioritize the development of services to agricultural producers and strengthen Agricultural Service Systems. This can be achieved through optimizing the public administration service system, establishing joint service organizations, and creating a good financial and legal service environment. By doing so, policymakers can promote the adoption of sustainable agricultural practices and the overall development of the agricultural sector.

KEYWORDS

agricultural socialized services, green production behaviour, smallholder farmers, rice production, China

1 Introduction

Smallholder farmers, commonly, farmers with less than 2 ha of cultivated land, produce about 80% of the world's food (Maass, 2013; FAO, 2014), which is vital to the global sustainable development (Fan and Rue, 2020). Smallholder farmers have long been at the centre of agricultural and rural development policies and strategies in the developing world (Bagheramiri and KeshvarzShaal, 2020). Despite their vital role, however, they are often more vulnerable to poverty and food insecurity (Alpízar et al., 2020; Adetoso et al., 2022). Consequently, agricultural practices conducted by smallholder farmers can be characterized as unproductive, unprofitable, environmentally-unfriendly and, as a result, unsustainable (Kandpal, 2021). Currently, in response to these critical challenges, the government of China identified two strategies: First, facilitating agricultural land transfer and scaling-up agricultural management system, thereby establishing large-scale agricultural operations, widely explained as agricultural economy of scale (Cao et al., 2020). Secondly, improving the quality of agricultural production operated by smallholder farmers through providing adequate services (Zhang, 2019; Yu et al., 2020). It's believed that providing multidimensional services to smallholders by creating special business enterprises can address these significant barriers and mobilize them towards sustainable agricultural development. Therefore, it's critical to investigate the effects of these services in changing the mode of smallholders' agriculture.

Agriculture is a major contributor to carbon emissions, and reducing these emissions is essential for mitigating the effects of climate change (Thomson et al., 2014; Karimi et al., 2018; Wagena and Easton, 2018; Sarkar et al., 2020; FAO, 2014; Lynch et al., 2021). For example, a study by FAO (2017) found that agriculture accounted for over one-quarter of energy-related CO_2 emissions in China. These findings highlight the urgent need for sustainable agricultural practices that can reduce carbon emissions and promote environmental sustainability. In this context, studying green production behavior of smallholder farmers in China becomes even more critical, as it could potentially identify approaches to mitigate the impact of agricultural activities on the environment (Li et al., 2020). By adopting sustainable agricultural practices, such as the use of organic fertilizers and conservation tillage, farmers can reduce their carbon footprint and contribute to the global effort to combat climate change (Huang et al., 2018). Therefore, investigating the impact of Agricultural Socialized Services (ASSs) on green production behavior is crucial, as these services provide smallholder farmers with access to information, resources, and technologies necessary for adopting sustainable agricultural practices and reducing carbon emissions.

The Chinese government promotes a special organized service system called agricultural socialized services (henceforth ASSs) to provide multidimensional services to smallholder farmers. ASSs refer to the various agricultural services provided by the social economic organizations to meet the needs of agricultural production and the business entities of agricultural production (Han et al., 2021; Salam et al., 2021; Yi et al., 2021). In recent years, ASSs have garnered the attention of smallholder farmers. Typical ASSs include agricultural machinery services, soil test-based, and organic fertilizer services, crop protection services, and other services put in place to support the sustainability of smallholders' agriculture. At present, ASSs serve as a key tool to improve the quality and productivity of agricultural production for smallholder farmers (Huan et al., 2022).

The expense of smallholders for the purchase of ASSs increased from 89.9 yuan per mu in 2004 to 272.26 yuan in 2019, accounting for 50% of the agricultural production costs (Mao et al., 2021). As of the end of 2020, the number of ASSs organizations in China had exceeded 900,000, and the agricultural production trusteeship service had exceeded 1.6 billion mu, including over 900 million mu of food crops, and over 70 million smallholder households. The government has also continually introduced a range of policies and measures to support the development of ASSs organizations. The report of the 19th National Congress of the Communist Party of China (herein after CPC) proposed to improve the ASSs system and realizing the organic connection between smallholder farmers and modern agriculture development. In 2021, the No.1 Document of the CPC again proposed the development and expansion professional ASSs organizations and the introduction of advanced and applicable varieties, inputs, technologies, and equipment to smallholder farmers. It can be seen that China's agricultural management departments have taken the ASSs as an important starting point to change the agricultural development mode. Moreover, ASSs are considered an effective path to guide smallholder farmers in achieving the organic connection of green production and modern agriculture. Therefore, in-depth efforts to investigate the impact of the ASSs on smallholders farmers agricultural production is an important response to practical problems.

In China, southern regions account for a majority of rice production, with approximately 90% of the country's rice grown in this area. However, despite this dominance in rice cultivation, small-scale farmers in these regions face significant challenges due to the impact of arable land area and population size. These farmers have very limited land area available for farming, which makes it difficult to achieve sustainable agricultural practices. Additionally, small-scale farmers in southern China have weak green production awareness and technical support, which exacerbates their difficulties in producing crops. The lack of knowledge and resources among small-scale farmers can lead to inefficient use of fertilizer, resulting in environmental pollution, decreased crop yields, and ultimately, economic losses (Guo et al., 2021). Therefore, it is crucial to provide agricultural socialized services to support these farmers and promote sustainable, efficient, and environmentally-friendly agricultural practices. By doing so, we can enhance green production behavior in smallholder farmers, particularly in the fertilization of rice production in southern China, and promote more sustainable and efficient use of resources.

Farmers' green agricultural production behaviour (henceforth GPB) refers to the intention of farmers to apply eco-friendly agricultural practices to improve the quality and safety of agricultural products thereby mediating agricultural environmental pollution (Gong et al., 2019; Shen et al., 2020; Xiao et al., 2022; Zhang et al., 2022). GPB usually has five main objectives: 1) pollution reduction 2) energy conservation 3) consumption reduction, and 4) high-quality and high-efficiency agricultural system 5) ecological and safe agricultural production methods by creating standardized agricultural operation methods (Liu et al., 2020; Pergola et al., 2020; Khanh Chi, 2022). Farmers' GPB includes the intention of applying soil and water conservation practice, application of organic fertilizers, straw applications and other eco-friendly agricultural practices (Muktamar et al., 2016; Alemayehu et al., 2020). GPB of smallholders is affected by multidimensional factors and understanding the complex mechanism how these factors influence on agro-environmental nexus is important form a policy perspective.

The aim of this paper is to investigate the impact of Agricultural Socialized Services (ASSs) on the Green Production Behavior (GPB) of smallholder rice farmers in south China, particularly in the application of organic and soil-tested fertilizers. The study collected survey data from three major rice production provinces in south China in 2020 and utilized an empirical model to conduct an exploratory analysis. By focusing on the most difficult agricultural management subject in China, the study provides a policy basis to encourage smallholder rice farmers to actively participate in green agricultural production and promote the high-quality development of agriculture. The study's contribution lies in measuring the level of local ASSs and avoiding endogenous problems between the production behavior of smallholder farmers and ASSs variables. Additionally, by taking the actual fertilization behavior of smallholder farmers as the main focus, the study avoids including GPBs that belong to the category of socialized services, making it easier to analyze the relationship between ASSs and the GPB of smallholder farmers. However, more elaboration is needed to clarify how ASSs can stimulate the GPB of smallholder farmers and why this is important for the development of green agricultural production.

2 Literature review

Over the past few years, literature has become increasingly interested in the multi-dimensional aspects of ASS. ASS are becoming a key tool in providing high-quality, profitable agricultural inputs to smallholder farmers (Lin et al., 2022). ASS provides a solution for farmers' employment decisions and address agricultural labor shortage (Chen et al., 2022; Cheng et al., 2022). ASS, by encouraging farmers to involve in farmland transaction market (farmland transfer-in and out), encourages smallholder farmers to participate in farmland scale management operations (Cai et al., 2022). ASS enhances crop yield and generate economic benefit (Zhang et al., 2018).

Existing studies have carried out extensive research on farmers' GPB. GPB affected by multidimensional factors. For instance, support policies for field guidance, machinery service and financial support service encourage farmers to use manure in their farmland (Zhang et al., 2022). Farmers who are members of agricultural cooperatives, obtained subsidies, and own vast agricultural lands tend to apply agricultural green production practices (Wang et al., 2018). However, unstable land tenure, small and fragmented agricultural land restrict GPB of farmers (Xu et al., 2014; Lu et al., 2019). Farmers with knowledge of agricultural land protection policies tend to apply agricultural green production practices (Cao et al., 2020). The provision of expertise and experience on the use of organic fertilisers and subsidies encourages farmers to use organic fertilisers (Vu et al., 2020; Zhang et al., 2021). These studies focused primarily on the mechanisms of factors that affect farmers' GPB. In China, the positive factors of GPB such as guidance, financial support and information provision have recently offered by ASSs.

Only few studies address the question of whether ASSs have contributes to the improvement of GPB of smallholder farmers such as the application of organic fertilizer and soil tested fertilizer by smallholders. For instance, existing studies highlighted the role of ASSs, particularly, ASS of organic and soil-tested fertilizer in improving soil quality and fertility (Han et al., 2021; Yi et al., 2021). Rice farmers who use ASSs are technically more efficient than those who do not, suggesting that organic fertilizers enable farmers to improve the agricultural green production efficiency of rice cultivation (Salam et al., 2021). ASSs encourage smallholder farmers to participate in the agricultural green revolution paradigm (Epule et al., 2015). The use of ASSs have reduced disruptions to ecosystems by inhibiting GHG emissions (Tang et al., 2019). ASSs promote agricultural cleaner production and quality development in the agricultural sector (Zhang, 2019; Ji and Li, 2020; Sun et al., 2020). Agricultural cleaner production aims to reduce the environmental impact of farming while maintaining or increasing productivity. Moreover, ASSs encourage smallholder farmers to adopt soil and water conservation practices such as crop rotation and manure application (Gideon, 2022). Recently, Huan et al. (2022) revealed that ASSs encourage farmers to adopt sustainable agricultural practices. Though ASSs emerging as an essential strategies to improve the quality and safety of smallholders' agricultural practices, the knowledge on the linkage between ASSs and GPB of smallholders is still insufficient.

3 Methods

3.1 Theoretical foundation

Macho-Stadler and Pérez-Castrillo, 2012 constructed a principal-agent model to examine the behavior of law enforcement officers. This model has attracted the attention and application of wider scholars to investigate problems such as moral hazard. Assuming that farmers are always engaged in agricultural production activities and belong to the type of risk neutrality. Farmers determine their production behavior according to the long-term effect obtained. There is two behaviors of farmers in the process of agricultural production; the behavior of implementing green agricultural practices and the behavior of non-implementing green production practices. Farmers who do not implement green production practices are mainly referred to farmers' illegal use of chemical fertilizers, pesticides, and other environmentally harmful chemicals, which is considered a moral hazard behavior.

In terms of the major factors affecting farmers' demand for chemical fertilizer, we agree that increasing production and risk avoidance are key drivers. We would like to further elaborate on the relevant theories in this regard. Behavioral economics theory suggests that farmers' decision-making can be influenced by psychological factors such as cognitive biases, emotions, and social norms. On the other hand, risk aversion theory suggests that farmers will be more cautious and conservative in their fertilizer use if they perceive high levels of risk associated with crop failure or financial loss. It is important to note that socialized services can provide support and incentives for small farmers to translate their willingness to adopt green practices into actual behavior. Socialized services can offer training programs, technical assistance, financial incentives, and access to markets, all of which can help to reduce the perceived risks of transitioning to more sustainable and environmentally friendly farming practices. In summary, behavioral economics and risk aversion theories explain the major factors affecting farmers' demand for fertilizers. Socialized services play a critical role in incentivizing the adoption of green practices among small farmers. We will make sure to strengthen the theoretical underpinnings of our paper accordingly.

Suppose that when farmers choose to implement GPBs, they expect their agricultural production income in each period $I_1 (I_1 > 0)$, C_1 represents the cost of agricultural production, represents the reward for implementing green production and ε (0 < ε < 1) represents the discount factor, then the utility function of the farmer in each period is $U = I_1 + R - C_1$.The expected utility flow of farmers is calculated as follows:

$$U_1 \; U_2 \;\ldots\ldots\; U_t$$
$$I_1 + R - C_1 \; I_1 + R - C_1 \; I_1 + R - C_1$$

When farmers implement GPBs, the expected total effect is:

$$TU_1 = U_1 + \varepsilon U_2 + \cdots + \varepsilon^{t-1}U_t = (I_1 + R - C_1)(1 + \varepsilon + \cdots + \varepsilon^{t-1}) = \frac{1-\varepsilon^t}{1-\varepsilon}(I_1 + R - C_1) \quad (1)$$

Since farmers clearly know that the government and consumers cannot monitor their production behavior all the time, they do not implement safe production behavior. The government cannot easily find farmers who implement non-green agricultural production practices. Therefore, farmers have the motivation to carry out moral hazard.

In order to achieve the goal of increasing production and income, farmers may increase the application of chemical fertilizers and pesticides, and even use illegal pesticides. It is assumed that the additional income obtained by farmers without implementing GPBs is B, the production cost is C2. Assuming that the cost of farmers implementing GPBs is greater than that of farmers not implementing GPBs, that is, C2 < C1, and they still choose not to implement GPBs in subsequent periods until they are found. If farmers do not implement GPBs and are not found, their income is $B + I_1 + R - C_2$;If a farmer is found not to implement GPBs, his income is $I_2 - F - C_2$, where I_2 represents the income of farmers who are found not to implement GPBs$(0 \le I_2 \le I_1)$,F represents the loss or cost of farmers' failure to implement GPBs under the background of organization, market and government supervision.

Assuming that the probability of non-GPBs farmers being discovered by consumers, p is represent the government or other clients, the expected utility of farmers in each period is:

$$U = (1-p)(B + I_1 + R - C_2) + p(I_2 - F - C_2)$$
$$U_1 = (1-p)(B + I_1 + R - C_2) + p(I_2 - F - C_2)$$
$$U_2 = (1-p)(B + I_1 + R - C_2) + p(I_2 - F - C_2)$$
$$\ldots\ldots$$
$$(1-p)(B + I_1 + R - C_2) + p(I_2 - F - C_2)$$
$$U_t = (1-p)(B + I_1 + R - C_2) + p(I_2 - F - C_2)$$

If farmers always choose not to implement GPBs, the expected total effect is:

$$TU_2 = U_1 + \varepsilon U_2 + \cdots + \varepsilon^{t-1}U_t \quad (2)$$
$$= [(1-p)(B + I_1 + R - C_2) + p(I_2 - F - C_2)](1 + \varepsilon + \cdots + \varepsilon^{t-1})$$
$$= \frac{1-\varepsilon^t}{1-\varepsilon}[(1-p)(B + I_1 + R - C_2) + p(I_2 - F - C_2)]$$
$$= \frac{1-\varepsilon^t}{1-\varepsilon}[(1-p)(B + I_1 + R - C_2) + p(I_2 - F - C_2) - p(I_2 - F - C_2)]$$

Whether farmers implement GPBs mainly depends on the extent to which these two behaviours happen which in turn affect farmers expected total utility. If the expected total utility of farmers increases after not GPBs, farmers will choose not to implement GPBs. The difference between the expected total utility of farmers implementing green production behavior (Eq. 1) and not implementing GPB (Eq. 2) is:

$$\Delta TU = TU_1 - TU_2 \quad (3)$$

in Eq. 3, Δ TU represents the increase of total utility when farmers implement GPBs. When the increase of total utility is greater than zero, farmers are willing to implement GPBs, and the more the increase of total utility, the stronger the willingness of farmers to implement GPBs.

Farmers are limited rational brokers, and their ultimate purpose in agricultural production activities is to obtain the maximum benefits. According to Eq. 3, it can be seen that whether farmers choose to implement GPBs may be affected by these factors including: rewards received by farmers from the government, cooperatives or enterprises when they implement green production behavior (R); the cost of agricultural production induced by farmers GPBs (C_1); income obtained from agricultural production when farmers implement GPBs (I_1); losses caused by the government, cooperatives, enterprises and other clients when farmers do not implement green production (F); the probability of being discovered and punished by the client when farmers do not implement GPBs (p); the extra income that farmers can get from agricultural production when they do not GPBs (B); the agricultural production income after the client finds when farmers do not implement GPBs (I_2) and agricultural production cost when farmers do not GPBs (C_2); income discount factor ε.

When we calculate the partial derivative of the above influencing factors according to Eq. 3, the impact of each factor on farmers' not to implement GPBs is as follows:

$$\frac{d\Delta TU}{dp} = \frac{1-\varepsilon^t}{1-\varepsilon}(B + R + F + I_1 - I_2) > 0 \quad (4)$$
$$\frac{d\Delta TU}{dI_2} = -\frac{1-\varepsilon^t}{1-\varepsilon}p < 0 \quad (5)$$
$$\frac{d\Delta TU}{dF} = \frac{1-\varepsilon^t}{1-\varepsilon}p > 0 \quad (6)$$
$$\frac{d\Delta TU}{dI_1} = \frac{1-\varepsilon^t}{1-\varepsilon}p > 0 \quad (7)$$
$$\frac{d\Delta TU}{dR} = \frac{1-\varepsilon^t}{1-\varepsilon}p > 0 \quad (8)$$
$$\frac{d\Delta TU}{dB} = -\frac{1-\varepsilon^t}{1-\varepsilon}(1-p) < 0 \quad (9)$$
$$\frac{d\Delta TU}{dC_1} = -\frac{1-\varepsilon^t}{1-\varepsilon} < 0 \quad (10)$$
$$\frac{d\Delta TU}{dC_2} = -\frac{1-\varepsilon^t}{1-\varepsilon}P > 0 \quad (11)$$

From the above analysis, it can be seen that if farmers do not implement the GPB, the penalty will be higher. On the other hand,

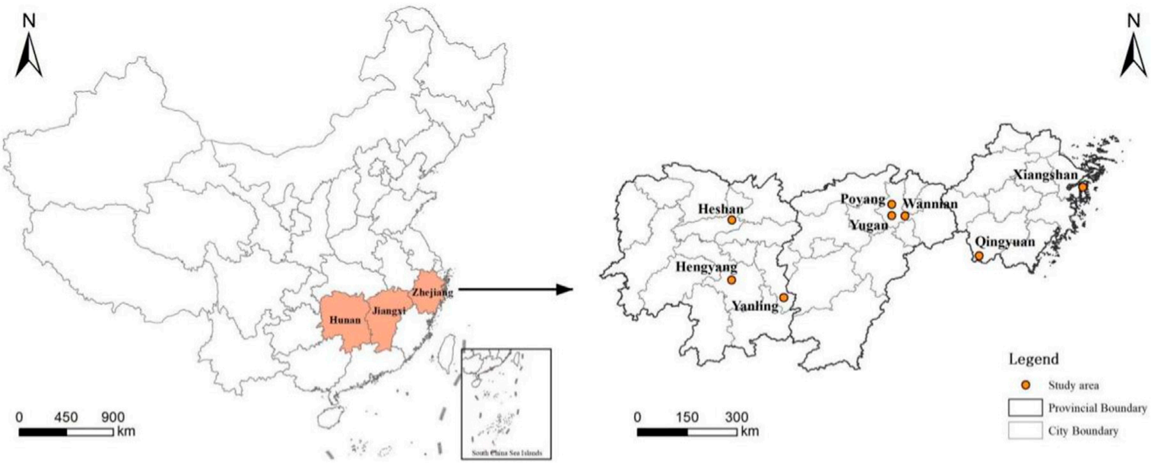

FIGURE 1
Map of the surveyed area.

the higher the income for implementing the GPB, the more rewards they will receive, and the lower the cost of implementing the GBP. This will motivate farmers to choose to implement the GPB. On the contrary, the higher the income of farmers who do not implement GPB, the higher the additional income of farmers who do not implement GPB, and the lower the cost of farmers who do not implement GPB, the greater the motivation of farmers to choose not to implement GPB.

By taking the fertilizer application behavior, this paper examines the GPB of smallholder farmers and defines the fertilization behavior with the green attribute as the application of soil testing formula fertilizer and organic fertilizer. The user behavior of soil testing formula fertilizer and organic fertilizer belong to two discrete selection variables; soil testing formula fertilizer (or organic fertilizer) has been applied, and the other soil testing formula fertilizer (or organic fertilizer) has not been applied. Smallholder farmers will be affected by many factors when using soil testing formula fertilizer and organic fertilizer. Therefore, the two decisions of smallholder farmers depend on each other. The interaction between the two decisions produces four results: Neither soil testing formula fertilizer nor organic fertilizer are applied; only soil testing formula fertilizer is applied; only organic fertilizer is applied and both soil testing formula fertilizer and organic fertilizer are applied.

3.2 Probit model

This paper establishes a bivariate probit model to analyse the impact of various factors on the green production behavior of small farmers. The model includes two binary models explained variable, the specific form of the model is as follows:

$$Y^{*}_{1i} = \beta'_{1} X_{i} + \varepsilon_{1i}$$
$$Y^{*}_{2i} = \beta'_{2} X_{i} + \varepsilon_{2i}$$

where Y^{*}_{1i} and Y^{*}_{2i} represent the selection of smallholder farmers for the application behavior of soil testing formula fertilizer and organic fertilizer respectively, i = 1, N represents the ith observation sample; X_i represents various factors affecting the behavior of small farmers in soil testing formula fertilizer and organic fertilizer application, β'_j (j = 1, 2) is the corresponding estimation coefficient. In this paper, Y_1 and Y_2 are used to represent the decision of smallholder farmers to apply soil testing formula fertilizer and organic fertilizer respectively. It is assumed that $Y_1 = 1$ means that small farmers apply soil testing formula fertilizer, and $Y_1 = 0$ means that smallholder farmers do not apply soil testing formula fertilizer. Similarly, $y_2 = 1$ means that smallholder farmers apply organic fertilizer, while $y_2 = 0$ means that small farmers do not apply organic fertilizer. Then the four results can be expressed as: (0, 0), (1, 0), (0, 1), (1, 1). Because the bivariate probit model allows the correlation between the error terms of different equations.

For the latent variable y*m, assume:

$$Yj = \begin{cases} 1 & \text{if } Ym > 0 \\ 0 & others \end{cases}$$

If smallholder farmers apply soil testing formula fertilizer, the choice of organic fertilizer is independent, then the above two equations are univariate probit model, ε_{mi} (m = 1,2) which is independent and identically distributed. However, if smallholder farmers apply soil testing formula fertilizer and organic fertilizer at the same time, the decisions are not mutually exclusive that ε_{mi} will obey multivariate normal distribution MVN $(0,\psi)$, and the covariance matrix ψ as follows:

$$\phi = \begin{bmatrix} 1 & \rho_{12} \\ \rho_{21} & 1 \end{bmatrix}$$

If the element value on the non-diagonal line is not 0, it indicates that the behavior of smallholder farmers applying soil-testing formula fertilizer and organic fertilizer is correlated, and the bivariate probit model should be used for regression analysis.

TABLE 1 Variable definitions and statistical description.

Variable	Definition	Mean	S.D.
Dependent variable	Yes = 1; No = 0	0.212	0.409
GPB			
Use of soil tested formula fertilizer	Yes = 1; No = 0	0.259	0.259
Use of organic fertilizer			
Independent variable			
ASSs	The actual expenditure of ASS for producing one season of rice per mu in the village where the smallholder farmers are located (yuan)	266.904	61.317
Development level of local ASS.			
Control variable			
Individual characteristics	Actual age of respondents (age)	61.690	9.558
Age	Education years of respondents (years)	3.984	3.118
Education	Years of migrant work of respondents (years)	4.574	6.599
Migrant work experience			
Family characteristics	No. of training (times)	0.433	1.326
Technical training	Total household income in 2019 (10,000 yuan)	9.523	1.058
Income level	Agricultural income/total household income in 2019 (%)	0.291	0.338
Proportion of agricultural production income	No. of college students in family members (person)	0.290	0.584
Human capital			
Farmland characteristics	Actual cultivated land area (mu)	4.652	3.358
Farmland area	Number of plots/actual cultivated plots (block/mu)	1.288	1.888
Farmland fragmentation	Flat = 1; A little slope = 2; Large slope = 3	1.827	0.788
Farmland levelling	1 = very poor; 2 = poor; 3 = general; 4 = better; 5 = very good	3.290	0.864
Farmland fertility			
Village characteristics	Distance to the nearest town (km)	5.713	4.062
Geographical position	Yes = 1, No = 0	0.173	0.378
Policy publicity			

The cost of farmers' agricultural production is related to the market and farmers' ability. Whereas, the income of farmers' agricultural products is related to the market. The probability of farmers not implementing green production behavior being found, as well as punishment and rewards obtained from implementing green production behaviors are related to the organization, the market, and the government. The analysis of the formation mechanism of green production behavior shows that whether smallholder farmers adopt green production technology is mainly affected by four factors: farmers themselves, the market, the organization, and the government (Liu et al., 2020). ASSs can enhance farmers' awareness and ability of small farmers of green agricultural production. ASSs support smallholder farmers to obtain better market information symmetry. Moreover, ASSs reduce the cost of smallholder farmers adopting green production technology and then promote smallholder farmers to adopt GPBs. Based on the above analysis, the study puts forward the hypothesis:

H1. ASSs have a positive impact on GPB of smallholder farmers in general.

H2. Smallholder farmers who obtained ASSs tend to apply organic fertilizer and soil-tested formulas more than those who do not.

Farmers' production behavior has both positive and negative external effects. In fact that farmers also judge the impact of their production behavior as it drives extensive attention from the government, social organizations, and consumers. If farmers do not implement green production, they may not be rewarded by agricultural cooperation organizations. The market or the government investigates and identifies farmers who do not implement green production. As a result, the reputation of the village will decline and affect the sales of agricultural products. Farmers who do not implement green production may be also excluded from other farmers who implement green production. On the contrary, if farmers choose to implement green production, they do not need to bear the huge

TABLE 2 Estimation results of the covariance matrix of the bivariate probit equation.

	Soil-tested formula fertilizer	Organic fertilizer
Soil-tested formula fertilizer	1	0.138***
Organic fertilizer	0.138***	1

Note: *, **, *** indicate statistical significance at the level of 10%, 5% and 1%, respectively.

psychological pressure and do not worry about being sampled by the organization, market, or government. They will earn a reputation for themselves and promote the sales of agricultural products due to long-term moral behaviors. Accordingly, this study consider internal and external factors, and theoretically analyses the main influencing factors of farmers' GPBs.

4 Data collection

The data utilized in this study were collected from rice planting smallholder household survey carried out between July and August 2020. A combination of stratification (counties and districts) and random sampling approach (village and towns) was used to collect the relevant data. Map of the study area is indicated in Figure 1. First, we purposively selected Hunan, Jiangxi and Zhejiang province, because they are the largest rice producing hub in the south China and are responsible for more than 25 percent of national rice production. Moreover, these provinces have a conducive climatic condition for rice production.

A total of 800 questionnaires were distributed, and 741 valid samples met the requirements of this study, with an effective rate of 92.63%. The questionnaire was formulated in accordance with the steps of design, pre-investigation, and finally editing the questionnaire to ensure that the content was clear, properly understood, and accepted by farmers in the face-to-face interviews. The interviews with farmers were conducted by a group of 12 research experts who are the members in our research team. Before the survey, to prove the trustworthiness and reliability of the survey data, the experts undertook training to ensure that the members fully understood the relevant issues in the questionnaire. The survey targeted rice farmers who use soil tested and organic fertilizer. The raw data were handled and analysed using stata14 to facilitate analysis.

Second, eight counties with higher rice production intensity were selected. Hengyang County, Yanling County and Yiyang County were sampled in Hunan; Wannian County, Poyang County and Yugan county were selected from Jiangxi province and Qingyuan County and Xiangshan County were selected from Zhejiang province. Third, households were selected from each counties based on the accessibility of ASSs including 228 households from counties in Hunan province; 334 households in Jiangxi province and 125 households in Zhejiang province. A total of 741 representative households were selected. Finally, a total of 800 questionnaires were distributed and 725 valid samples met the requirement of this study, with an effective rate of 90.63 percent.

In the selection of sample farmers, the regional development level, geographical location and relevant agricultural natural resource endowment were fully considered. The questionnaire was prepared in English and later translated into Chinese. We then trained the enumerators and conducted a pre-test to re-check the validity of the interview process. Face-to-face interviews were monitored by the authors and carried out by enumerators who are members of the research group and able to speak both Mandarin and the local language. In terms of survey content, the questionnaire covers the rice production season of smallholder farmers' from 2018 to 2019, and data such as basic characteristics of smallholder farmers' family endowment, purchase of ASSs, cultivated land management, geographical location of villages and other relevant data according to the purpose of this study were collected.

4.1 Variable selection and descriptive statistics

The dependent variable in this study is the GPB, which is the behavior of smallholder farmers applying soil-tested formula fertilizer and organic fertilizer. Therefore, there are two dependent variables in this paper; the use of soil-tested formula fertilizer and the use of organic fertilizer. If farmers applied any of these GPB, they will assign the value 1, otherwise the value will be 0. In this study, smallholder farmers' GPB considered a mechanism to combat the agricultural non-point source pollution through reducing the application of chemical fertilizer. Thus, farmers' GPB can promote green agricultural production development in the study area.

This study takes ASSs level as the independent variable and calculated the average expenditure of ASSs for one season of rice per mu in the village where smallholder farmers are located to measure the local development level of ASSs. Table 1 shows the dependant variable and it's definition. Compared with the availability indicators such as whether there are local ASSs, the average expenditure on ASSs can better represent the development level of ASSs.

Control variables in this study not only affect both ASSs and GPB but also differentiate smallholder farmers who use ASSs from non-users. A detailed description of the controlled variable and the variable definition is presented in Table 1. The study identified the individual characteristics of farmers (age, educational level, migrant work experience, and agricultural technology training experience), family characteristics (income level, family business type, and human capital), farmland characteristics (farmland area, the degree of farmland fragmentation, farmland levelling, and farmland fertility status), and village characteristics. The characteristics of the village mainly include the geographical location of the village and whether the local government has publicized agricultural green production policies in the village.

Diversity in ages, education status, work experience and agriculture technology training experience causes the difference in the supply and quality of agricultural labor in the rice production, and their perception of utilizing ASSs would also vary, therefore, the decision to use ASSs will be different among farmers. Family behaviour such as income level and family business type will directly affect the use of ASSs. Human capital indicates the

TABLE 3 Estimation results of the impact of ASSs on the GPB of smallholder farmers (ordinal probit model).

Variables	Model 1		Model 2	
	Soil testing formula fertilizer		Organic fertilizer	
	Coefficient	S.E	Coefficient	S.E.
ASSs	0.535**	0.259	0.653***	0.251
Age	−0.006	0.006	0.012**	0.006
Education level	0.031*	0.018	−0.015	0.018
Migrant work experience	0.002	0.009	0.005	0.008
Participate in technical training	0.098***	0.037	−0.182***	0.063
Income level	−0.017	0.042	0.046	0.041
Proportion of agricultural production income	−0.074	0.190	−0.197	0.195
Human capital	0.035	0.092	0.191**	0.089
Farmland area	0.017	0.018	0.013	0.018
Fragmentation degree of farmland	−0.006	0.034	0.001	0.036
Farmland levelling	−0.081	0.147	−0.282*	0.149
Farmland quality	0.036	0.067	0.200***	0.068
Geographic location	0.017	0.028	0.048*	0.028
Policy publicity	0.003	0.147	0.608***	0.133
Constant term	−3.580**	1.520	−6.039***	1.504
Number of samples	741		741	
p-value	0.0180		0.0000	

Note: *, **, *** indicate statistical significance at the level of 10%, 5%, and 1%, respectively.

number of college students in family members has effects on the use of ASSs. Since college students expected to have awareness and knowledge, households with college students will use more ASSs. College Students Going to the Countryside during Summer" is an annual event in China where college students promote green production policies and practices to small farmers. During this event, students provide education and support on sustainable agricultural practices such as the use of organic fertilizers and soil-tested formula fertilizers. The presence of college students can positively influence attitudes and behaviors towards green production among smallholders. By empowering small farmers to adopt sustainable practices, this initiative contributes to the long-term viability of their farms and supports larger societal goals of promoting environmentally-friendly practices and sustainable economic development. Additionally, the involvement of college students in promoting green production policies can bring attention to the importance of sustainability and contribute to its prioritization in decision-making.

The farmland endowment will create difference among smallholder farmers utilization behaviour of utilizing ASSs. Farmers with higher farmland endowment will have higher expenditure on purchasing ASSs. Farmland fragmentation has effect on the purchasing power of ASSs among smallholder farmers in that farmers with high degree of fragmented land spend less expenditure to purchase ASSs. The topography and quality of farmland also have effect on farmers ability of purchasing ASSs. Farmers who have fertile land will spend less to purchase ASSs than the counters. The geographical location of the village where smallholder farmers located has its own effect on the ASSs level. For instance, village with advanced infrastructure and near to urban area will purchase more ASSs than the counters because they will have other non-farm employment opportunities that provide additional income which improves their capacity of purchasing more ASSs. Farmers found in the villages with access to the government publicity of agricultural green production policies will have more information that enables them to have awareness to utilize ASSs.

4.2 Statistical analysis

Table 1 presents the definition and the descriptive statistics of variables used to examine the effect of ASSs on GAP of smallholder farmers. It can be seen that 21.2% of smallholder farmers in the study area have applied soil-tested formula fertilizer and 25.9% of smallholder farmers have applied organic fertilizer. This show that the overall proportion of smallholder farmers adopting the GPB is

TABLE 4 Estimation results of the influence of ASSs on the GPB of smallholder farmers (bivariate probit model).

Variables	Model 1		Model 2	
	Soil-tested formula fertilizer		Organic fertilizer	
	Coefficient	S.E.	Coefficient	S.E.
ASS	0.516**	0.258	0.641***	0.250
Age	−0.006	0.006	0.012*	0.006
Education level	0.032*	0.018	−0.014	0.018
Migrant work experience	0.002	0.008	0.005	0.008
Participate in technical training	0.099***	0.037	−0.188***	0.065
Income level	−0.016	0.042	0.049	0.041
Proportion of agricultural production income	−0.058	0.189	−0.168	0.195
Human capital	0.034	0.092	0.195***	0.089
Farmland area	0.017	0.018	0.012	0.018
Fragmentation degree of farmland	−0.006	0.034	−0.001	0.037
Farmland levelling	−0.076	0.146	−0.279*	0.149
Farmland quality	0.039	0.068	0.198***	0.068
Geographical location	0.016	0.027	0.048*	0.028
Policy publicity	−0.007	0.147	0.604***	0.133
Constant term	−3.511**	1.518	−5.996***	1.502
Number of samples	741			
p-value	0.0000			

Note: *, **, *** indicate statistical significance at the level of 10%, 5% and 1%, respectively.

still relatively low and has more place for improvement. The estimation result shows that in one season, the average expenditure of ASSs per mu in the village where smallholder farmers are located was 266.9 yuan. This shows that farmers use ASSs only for small proportion of rice production practices and in general the ASSs development level in the study area is low. The average age of farmers is 61.9 years, which shows that the rice production area is dominated by older farmers. Most of the respondents spend an average of 3.9 schooling years indicating that the respondents are completed only primary school. The average migrant work experience is 4.5 years.

Farmers have few training opportunities (0.43 times) and the total household income is 95, 230 yuan. The proportion of the average agricultural production income is 21.9%. Among the respondents, 21% of the household has at least one member of college student. The actual farmland area of households is 4.652 mu, which indicates that their land endowment is far lower than the national average and the average fragmentation degree of their farmland, which is calculated as number of plots/actual cultivated plots, is 1.288 block/mu, shows higher fragmentation rate. The majority of farmlands of the smallholder farmers is little slop (1.827). The average fertility status of the household in the study area is almost good (3.290). The average distance of farmers from the nears home town is 5.713 km. From the respondents, only a small proportion of respondents can access the government policy publicity (17.3%).

5 Results and discussion

5.1 Covariance matrix analysis

The covariance matrix results in Table 2 show that the correlation coefficient (ρ value) is 0.138, which is significant at the level of 1%, indicating that there is indeed a complementary effect between the application of soil testing formula fertilizer and organic fertilizer by smallholder farmers in the sample. Smallholder farmers applying organic fertilizer during rice planting are also more likely to apply soil-tested fertilizer, which is suitable for using the bivariate probit model.

5.2 The impact of ASSs on the GPB of smallholder farmers based on ordinal probit model

The ordinary probit model empirical analysis results of the impact of ASSs on the GPB of smallholder farmers are presented in Table 3. In Model 1, the impact of ASSs on the application of soil-tested formula fertilizer was presented, and the analysis was made based on the ordinary probit model. ASSs was used as an independent variable. The results show that the coefficient of ASS is 0.535 and significant at the 5% level, indicating that ASS has a significant, positive impact on smallholder farmers' application of soil-tested formula fertilizer in rice production. Moreover, the coefficient of farmers' participation in technical training and education level are 0.098 and 0.031 and significant at 1% and 10%, respectively. This indicates that farmers' participation in various training and their education level has a significant positive effect on the GPBs smallholder farmers. In Model 2, the impact of ASSs on the application of organic fertilizer was presented. The analysis was made based on the ordinary probit model and ASSs was also used as an explanatory variable. The results show that the coefficient of ASSs is 0.653 and significant at the 1% level, indicating that ASS has a significant, positive impact on smallholder farmers' application of organic fertilizer in rice production. This finding is consistence with Epule et al., 2015, found that ASSs encourage smallholder farmers to participate in the agricultural green revolution paradigm. Moreover, age, human capital, farmland levelling, farmland quality, geographic location, and policy publicity have a significant positive impact on the application of organic fertilizer. Table 3 shows the estimation results of the ordinary probit model. From the point of view of the *p*-value, the overall estimation effect of the two models is relatively good and the model estimation results are robust.

5.3 The impact of ASSs on the GPB of smallholder farmers based on bivariat probit model

The bivariate probit model analysis results in Table 4 show that ASSs have a significant and positive impact on smallholder farmers' GPB, which confirmed the H1. In Model 1, the impact of ASSs on the application of soil-tested formula fertilizer was presented. The results show that the coefficient of ASS is 0.516 and significant at the 5% level, indicating that ASSs have a significant, positive impact on smallholder farmers' application of soil-tested formula fertilizer in rice production, which confirmed the H2. Moreover, the coefficient of farmers' participation in technical training and education level are 0.099 and 0.032 and significant at 1% and 10%, respectively. This indicates that farmers' participation in various training and with higher education levels has a significant positive effect on the GPB smallholder farmers. In Model 2, the impact of ASSs on the application of organic fertilizer was presented. The results show that the coefficient of ASS is 0.641 and significant at the 1% level, indicating that ASSs have a significant, positive impact on smallholder farmers' application of organic fertilizer in rice production, which confirmed the H2. Moreover, age, human capital, farmland levelling, farmland quality, geographic location, and policy publicity have a significant positive impact on the application of organic fertilizer.

Agricultural green production provides substantial benefits in the reduction of agricultural non-point source pollution (Liu et al., 2020). Smallholder farmers contribute to improving environmental quality by adopting green agricultural production practices. However, they cannot fully obtain the corresponding compensation. In most cases, rational smallholder farmers who struggle to survive to tend to avoid the risks by maintaining a high dosage of chemical fertilizers and pesticides to maximize the production profit. Thus, it is critical to provide a novel framework to harmonize farmers and environmental demand, refers to balancing the economic needs of smallholder farmers while protecting the environment. ASSs can significantly change farmers' factor input and agricultural production management mode. Moreover, ASSs assist farmers to purchase the standard agricultural input (such as soil-tested formula fertilizer and organic fertilizer) which was difficult to find in the normal market. The agricultural input delivered by ASSs is scientifically selected, realizes the input of pro-environment factors of production, and can be purchased at a reasonable price. Due to the large-scale procurement, ASSs organizations have stronger negotiation ability in the factor-input trading market. As a result, if smallholder farmers participate in ASSs, they can obtain a cheaper supply of production factors to effectively reduce production costs. In addition, ASSs organizations rely on the introduction of professionals and technical equipment to introduce the concept of green agricultural production into the process of agricultural production, to promote small farmers to think and make decisions on the green attribute of input factors.

Beside ASSs, the education level and participation in technical training have a significant positive impact on the application of soil testing formula fertilizer and organic fertilizer by smallholder farmers. Both education level and participation in technical training belong to knowledge-based variables. It can be seen that soil testing formula fertilizer is a knowledge-intensive agricultural production factor, because when soil testing formula fertilizer is applied, farmers need to understand the whole process of soil testing formula technology from field experiment to effect evaluation, and master the knowledge of fertilization time, fertilizer formula and fertilization methods in different growth periods of crops. Age, participation in technical training, human capital, cultivated land levelling, cultivated land quality, geographical location, policy publicity and other variables have a significant impact on the application of organic fertilizer by small farmers. Among them, age is positively correlated with the behavior of small farmers in applying organic fertilizer, indicating that older small farmers prefer to apply organic fertilizer. According to the actual investigation, older small farmers use some farm manure because of their original production habits and the opportunity to save the cost of applying chemical fertilizer. Older small farmers have rich farming experience and are more able to bear hardships.

On the contrary, smallholder farmers are more likely to use organic fertilizer. The variable of participating in technical training is negatively correlated with the behavior of small farmers applying organic fertilizer, which may be mainly because the technical training at the grass-roots level in the past emphasized the importance of modern production factors and had the goal orientation of increasing grain production; The change of human capital is positively related to the behavior of small farmers applying organic fertilizer. This paper uses the number of college students in the family as the measurement standard. College students are high-quality human capital in the family, which will enhance the green concept of the family and urge the family to adopt green production behavior. There is a negative correlation between cultivated land levelling and the behavior of small farmers applying organic fertilizer, which shows that the flatter the cultivated land is, the smaller farmers tend to apply organic fertilizer.

The high-standard farmland being vigorously promoted in China is conducive to encouraging small farmers to apply organic fertilizer. The cultivated land quality variable is positively correlated with the behavior of smallholder farmers applying organic fertilizer. When the fertility of cultivated land is good, farmers tend to apply little organic fertilizer and *vice versa*. Farmers tend to use less organic fertilizer when the fertility of their land is high and more when it's poor. This may be due to a cost-saving perspective as excess fertilizer can result in a surplus of nutrients that may not be fully used by crops. Thus, to avoid waste, small farmers reduce the amount of fertilizer used when the fertility of their land is high. Conversely, increasing fertilizer application on low fertility land can replenish depleted nutrients and increase crop yield. Therefore, to increase yield, farmers tend to apply more fertilizer to lower fertility land. The geographical location variable is positively correlated with the behavior of small farmers applying organic fertilizer, indicating that the farther away from the nearest township government, the smaller farmers tend to apply organic fertilizer, which may be because the farther away from the market, the higher the cost of agricultural materials such as chemical fertilizer, which makes small farmers more willing to apply organic fertilizer such as farm fertilizer. The policy publicity variables are positively correlated with the behavior of small farmers applying organic fertilizer, indicating that small farmers who have heard the government's publicity of green production behavior in the villages are conducive to guiding small farmers to apply organic fertilizer.

In China, smallholder farmers will continue to play a pivotal role in the agricultural production sector. However, insufficient attention deteriorates the quality and the quality of their farming practices. In some cases, policies are biased to large farm holders and other agricultural entities than smallholder farmers. In particular, agricultural production services such as ASSs mainly subsidised and promoted to support large holder farmers which ignore smallholder farmers to involve in green agricultural production practices. Therefore, this study urges policymakers to pay proper attention for smallholder farmers through ASSs to improve the quality of their production such as adopting green agricultural inputs.

6 Conclusion and policy implications

Promoting the green development of agriculture is the bridge to realizing agricultural modernization and the trend of sustainable agricultural development in the future. Farmers' GPB such as the application of soil-tested formula fertilizer and organic fertilizer in rice production are crucial for the reduction of agriculture based environmental pollution. This study is based on the field survey data of 741 smallholder rice farmers in Hunan, Jiangxi, and Zhejiang provinces in China, using a probit model to determine the proportion of smallholder farmers who applied soil-tested formula fertilizer and organic fertilizer and the actual expenditure of smallholder farmers to purchase ASSs, studying the effect of ASSs utilization on the GPB, and to compare and discuss other factors effects on GPB of smallholder farmers. Based on the finding of this study, we draw the following conclusion:

First, the empirical analysis results revealed that at present, the proportion of smallholder farmers applying soil testing formula fertilizer and organic fertilizer in the rice production region of southern China is 21.2% and 25.9% respectively, indicating that the overall proportion is still relatively low. Second, ASSs can significantly promote the GPB of smallholder farmers. Third, the actual expenditures of ASSs influence smallholder farmers to apply soil testing formula fertilizer and organic fertilizer. The higher the price of ASSs, the more farmers tend to reduce the application of soil testing formula fertilizer and organic fertilizer which negatively affects the GPB of smallholder farmers.

To create an organic connection between smallholder farmers and modern agricultural development and further enhance the participation of smallholder farmers in green agricultural production, this study insights the following policy recommendations:

Several policy recommendations and constructive solutions can be suggested based on the findings of this study. Firstly, to increase the coverage of agricultural socialized services (ASSs), policymakers can consider expanding the funding support for these services or incentivizing agricultural service providers to offer services to more smallholder farmers in the southern China region. This could potentially enhance the GPB of smallholder farmers, as the study found that ASSs have a significant and positive impact on GPB. Secondly, policymakers can increase the awareness of green production practices among smallholder farmers through training and capacity-building programs. This could promote the adoption of green production practices and improve agricultural productivity, as the study found that farmers who obtained ASSs tend to apply organic and soil-tested fertilizers more frequently than those who did not.

Thirdly, optimizing the public administration service system could further strengthen ASSs. By streamlining administrative procedures and providing more efficient and effective services to agricultural producers, policymakers could improve the delivery of ASSs and enhance their impact on smallholder farmers' GPB. Fourthly, establishing a joint service organization could also strengthen ASSs. Setting up a platform for different stakeholders to collaborate and coordinate their efforts in promoting GPB among smallholder farmers could facilitate the sharing of knowledge, expertise, and resources, and promote the integration of different types of ASSs. Lastly, creating a good financial and legal service environment could strengthen ASSs by providing financial incentives and legal protections for agricultural service providers who offer ASSs to smallholder farmers. This could encourage more providers to offer ASSs and ensure their sustainability and effectiveness over time. In summary, policymakers could consider implementing these policy recommendations and solutions to promote the adoption of green production practices and enhance the GPB of smallholder farmers in southern China.

Despite the contributions of this study to the field, there are some limitations that should be acknowledged. Firstly, the sample size used in this study is relatively small as it was conducted only in three provinces in southern China. Therefore, it may not be sufficient to generalize the results to other regions or even other countries. Secondly, the study only focused on the impact of ASSs on fertilization behavior, but did not examine other green production behaviors of smallholder farmers. Future studies can expand the analysis to other behaviors such as irrigation, pest management, and harvesting. Finally, the study only examined the impact of ASSs from the perspective of smallholder farmers, but did not investigate the perspectives of other stakeholders such as government agencies, agricultural service providers, and consumers. Thus, a more comprehensive investigation is needed to understand the effectiveness of ASSs in promoting GBP.

This study opens up several avenues for future research. Firstly, future studies can expand the investigation to include other regions in China or even other countries to enhance the generalizability of the findings. Secondly, future research can focus on other green production behaviors beyond fertilization to provide a more comprehensive understanding of the effectiveness of ASSs. Thirdly, future research can examine the perspectives of various stakeholders and explore the interplay between them to provide a more holistic view of the impact of ASSs on GBP. Fourthly, future research can employ other statistical models beyond the probit model used in this study to provide more robust evidence. Finally, future research can explore the use of emerging technologies such as artificial intelligence and blockchain to enhance the effectiveness of ASSs in promoting GBP.

Data availability statement

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

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

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

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References

Adetoso, A., Mjabuliseni, S., Gideon, D., Temitope, O., and Abiodun, A. (2022). Impact of irrigation on welfare and vulnerability to poverty in South African farming households. *Sci. Afr.* 16, e01177. 2468-2276. doi:10.1016/j.sciaf.2022.e01177

Alemayehu, G., Shibabaw, A., Adgo, E., Asch, F., and Freyer, B. (2020). Crop rotation and organic matter application restore soil health and productivity of degraded highland crop farms in northwest Ethiopia. *Cogent Food Agric.* 6 (1), 1831124. doi:10.1080/23311932.2020.1831124

Alpízar, F., Saborío-Rodríguez, M., Martínez-Rodríguez, M. R., Viguera, B., Vignola, R., Capitán, T., et al. (2020). Determinants of food insecurity among smallholder farmer households in central America: Recurrent versus extreme weather-driven events. *Reg. Environ. Change* 20, 22. doi:10.1007/s10113-020-01592-y

Bagheramiri, Z., and KeshvarzShaal, F. (2020). "Smallholder farmers' role in sustainable development," in *Zero hunger. Encyclopedia of the UN sustainable development goals*. Editors W. Leal Filho, A. Azul, L. Brandli, P. Özuyar, and T. Wall (Cham: Springer). doi:10.1007/978-3-319-69626-3_47-1

Cai, B., Shi, F., Huang, Y., and Abatechanie, M. (2022). The impact of agricultural socialized services to promote the farmland scale management behavior of smallholder farmers: Empirical evidence from the rice-growing region of southern China. *Sustain. Switz.* 14 (1), 316. doi:10.3390/su14010316

Cao, H., Zhu, X., Heijman, W., and Zhao, K. (2020). The impact of land transfer and farmers' knowledge of farmland protection policy on pro-environmental agricultural practices: The case of straw return to fields in Ningxia, China. *J. Clean. Prod.* 277, 123701. doi:10.1016/j.jclepro.2020.123701

Chen, T., Rizwan, M., and Abbas, A. (2022). Exploring the role of agricultural services in production efficiency in Chinese agriculture: A case of the socialized agricultural service system. *Land* 11 (3), 347. doi:10.3390/land11030347

Cheng, L., Cui, Y., Duan, K., and Zou, W. (2022). The influence of new agricultural business entities on farmers' employment decision. *Land* 11 (1), 112. doi:10.3390/land11010112

Epule, E. T., Bryant, C. R., Akkari, C., and Daouda, O. (2015). Can organic fertilizers set the pace for a greener arable agricultural revolution in africa? Analysis, synthesis and way forward. *Land Use Policy* 47, 179–187. doi:10.1016/j.landusepol.2015.01.033

Fan, S., and Rue, C. (2020). "The role of smallholder farms in a changing world," in *The role of smallholder farms in food and nutrition security*. Editors Y. Gomez, S. Paloma, L. Riesgo, and K. Louhichi (Cham: Springer). doi:10.1007/978-3-030-42148-9_2

FAO (2014). *The state of food and agriculture: Innovation in family farming food and agriculture organization of the united nations.*

Food and Agriculture Organization of the United Nation (FAO) (2017). The share of agriculture in total greenhouse gas emissions Global, regional and country trends 1990–2017. Available at: https://www.fao.org/3/ca8389en/CA8389EN.

Gideon, D. (2022). Do agricultural extension services promote adoption of soil and water conservation practices? Evidence from northern Ghana. *J. Agric. Food Res.* 10, 100381. 2666-1543. doi:10.1016/j.jafr.2022.100381

Gong, J., He, C., and Zeng, F. (2019). *The realization mechanism of farmers' green production behavior: Based on the perspective of farmers' green production awareness and behavior differences*. Wuhan: Huazhong Agricultural University, 68–76.

Guo, L., Li, H., Cao, X., Cao, A., and Huang, M. (2021). Effect of agricultural subsidies on the use of chemical fertilizer. *J. Environ. Manag.* 299, 113621. doi:10.1016/j.jenvman.2021.113621

Han, J., Dong, Y., and Zhang, M. (2021). Chemical fertilizer reduction with organic fertilizer effectively improve soil fertility and microbial community from newly cultivated land in the Loess Plateau of China. *Appl. Soil Ecol.* 165, 103966. doi:10.1016/j.apsoil.2021.103966

Huan, M., Li, Y., Chi, L., and Zhan, S. (2022). The effects of agricultural socialized services on sustainable agricultural practice adoption among smallholder farmers in China. *Agronomy*. Beijing: MDPI 12 (9), 2198. doi:10.3390/agronomy12092198

Huang, M., Zhou, X., and Zou, Y. (2018). Improving nitrogen management for zero-tillage rice in China. *Crop J.* 6 (4), 406–412. doi:10.1016/j.cj.2018.03.002

Ji, M., and Li, L. (2020). Agricultural production trusteeship: The main forms of agricultural service scale operation. *Agric. Econ. issues* (1), 68–75.

Kandpal, G. (2021). Review on impact of chemical fertilizers on environment. *Int. J. Mod. Agric.* 10 (1) 758–763.

Karimi, V., Karami, E., and Keshavarz, M. (2018). Climate change and agriculture: Impacts and adaptive responses in Iran. *J. Integr. Agric.* 17 (1), 1–15. doi:10.1016/S2095-3119(17)61794-5

Khanh Chi, N. T. (2022). Driving factors for green innovation in agricultural production: An empirical study in an emerging economy. *J. Clean. Prod.* 368, 132965. doi:10.1016/j.jclepro.2022.132965

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

Lin, Y., Hu, R., Zhang, C., and Chen, K. (2022). The role of public agricultural extension services in driving fertilizer use in rice production in China. *Ecol. Econ.* 200, 107513. doi:10.1016/j.ecolecon.2022.107513

Liu, Y., Sun, D., Wang, H., Wang, X., Yu, G., and Zhao, X. (2020). An evaluation of China's agricultural green production: 1978–2017. *J. Clean. Prod.* 243, 118483. doi:10.1016/j.jclepro.2019.118483

Lu, H., Zhang, P., Hu, H., Xie, H., Yu, Z., and Chen, S. (2019). Effect of the grain-growing purpose and farm size on the ability of stable land property rights to encourage farmers to apply organic fertilizers. *J. Environ. Manag.* 251, 109621. doi:10.1016/j.jenvman.2019.109621

Lynch, J., Cain, M., Frame, D., and Pierrehumbert, R. (2021). Agriculture's contribution to climate change and role in mitigation is distinct from predominantly fossil CO2-emitting sectors. *Front. Sustain Food Syst.* 3 (4), 518039. doi:10.3389/fsufs.2020.518039

Maass, W. (2013). "Coping with the food and agriculture challenge: Smallholders' agenda," in Proceedings of the 2012 United Nations Conference on Sustainable Development.47.

Macho-Stadler, I., and Pérez-Castrillo, D. (2012). "Principal-agent models," in *Computational complexity*. Editor R. Meyers (New York, NY: Springer). doi:10.1007/978-1-4614-1800-9_140

Mao, D., Li, L., Lu, Q., and Cai, B. (2021). Thoughts on promoting the construction of "three products and one standard" with agricultural socialized services - based on the research on fujian agricultural production trusteeship service. *Rural. Work Commun.* 18, 41–43.

Muktamar, Z., Putri, D., and Setyowati, N. (2016). Reduction of synthetic fertilizer for sustainable agriculture: Influence of organic and nitrogen fertilizer combination on growth and yield of green mustard. *Int. J. Adv. Sci. Eng. Inf. Technol.* 6 (3), 361. doi:10.18517/ijaseit.6.3.802

Pergola, M., Persiani, A., Pastore, V., Palese, A. M., D'Adamo, C., de Falco, E., et al. (2020). Sustainability assessment of the green compost production chain from agricultural waste: A case study in southern Italy. *Agronomy* 10 (2), 230. doi:10.3390/agronomy10020230

Salam, M. A., Sarker, M. N. I., and Sharmin, S. (2021). Do organic fertilizer impact on yield and efficiency of rice farms? Empirical evidence from Bangladesh. *Heliyon* 7 (8), e07731. doi:10.1016/j.heliyon.2021.e07731

Sarkar, D., Kar, S. K., Chattopadhyay, A., ShikhaRakshit, A., Tripathi, V. K., Dubey, P. K., et al. (2020). Low input sustainable agriculture: A viable climate-smart option for boosting food production in a warming world. *Ecol. Indic.* 115, 106412. doi:10.1016/j.ecolind.2020.106412

Shen, J., Zhu, Q., Jiao, X., Ying, H., Wang, H., Wen, X., et al. (2020). Agriculture green development: A model for China and the world. *Front. Agric. Sci. Eng.* 7 (1), 5. doi:10.15302/J-FASE-2019300

Sun, X., Misgina, A., Lu, Y., Liu, M., and Zhu, Y. (2020). Genome-wide analysis reveals the association between alternative splicing and DNA methylation across human solid tumors. *Agric. Technol. Econ.* 4 (1), 4–15. doi:10.1186/s12920-019-0654-9

Tang, Q., Ti, C., Xia, L., Xia, Y., Wei, Z., and Yan, X. (2019). Ecosystem services of partial organic substitution for chemical fertilizer in a peri-urban zone in China. *J. Clean. Prod.* 224, 779–788. doi:10.1016/j.jclepro.2019.03.201

Thomson, A. M., Kyle, G. P., Zhang, X., Bandaru, V., West, T. O., Wise, M. A., et al. (2014). The contribution of future agricultural trends in the US Midwest to global climate change mitigation. *Glob. Environ. Change* 24, 143–154. doi:10.1016/j.gloenvcha.2013.11.019

Vu, H. T., Tran, D., Goto, D., and Kawata, K. (2020). Does experience sharing affect farmers' pro-environmental behavior? A randomized controlled trial in vietnam. *World Dev.* 136, 105062. doi:10.1016/j.worlddev.2020.105062

Wagena, M. B., and Easton, Z. M. (2018). Agricultural conservation practices can help mitigate the impact of climate change. *Sci. Total Environ.* 635, 132–143. doi:10.1016/j.scitotenv.2018.04.110

Wang, Y., Zhu, Y., Zhang, S., and Wang, Y. (2018). What could promote farmers to replace chemical fertilizers with organic fertilizers? *J. Clean. Prod.* 199, 882–890. doi:10.1016/j.jclepro.2018.07.222

Xiao, S., He, Z., Zhang, W., and Qin, X. (2022). The agricultural green production following the technological progress: Evidence from China. *Int. J. Environ. Res. Public Health* 19, 9876. doi:10.3390/ijerph19169876

Xu, H., Huang, X., Zhong, T., Chen, Z., and Yu, J. (2014). Chinese land policies and farmers' adoption of organic fertilizer for saline soils. *Land Use Policy* 38, 541–549. doi:10.1016/j.landusepol.2013.12.018

Yi, X., Yu, L., Chang, S. H. E., Yin, C., Wang, H., and Zhang, Z. (2021). The effects of China's Organic-Substitute-Chemical-Fertilizer (OSCF) policy on greenhouse vegetable farmers. *J. Clean. Prod.* 297, 126677. doi:10.1016/j.jclepro.2021.126677

Yu, Y., Jiang, T., Li, S., Li, X., and Gao, D. (2020). Energy-related CO2 emissions and structural emissions' reduction in China's agriculture: An input–output perspective. *J. Clean. Prod.* 276, 124169. doi:10.1016/j.jclepro.2020.124169

Zhang, H. (2019). Historical opportunities of agricultural productive service industry. *Rural Discov. China* (1), 47–53.

Zhang, M., Yao, Y., Tian, Y., Ceng, K., Zhao, M., Zhao, M., et al. (2018). Increasing yield and N use efficiency with organic fertilizer in Chinese intensive rice cropping systems. *Field Crops Res.* 227, 102–109. doi:10.1016/j.fcr.2018.08.010

Zhang, T., Hou, Y., Meng, T., Ma, Y. F., Tan, M. X., Zhang, F. S., et al. (2021). Replacing synthetic fertilizer by manure requires adjusted technology and incentives: A farm survey across China. *Resour. Conservation Recycl.* 168, 105301. doi:10.1016/j.resconrec.2020.105301

Zhang, T., Meng, T., Hou, Y., Huang, X., and Oenema, O. (2022). Which policy is preferred by crop farmers when replacing synthetic fertilizers by manure? A choice experiment in China. *Resour. Conservation Recycl.* 180, 106176. doi:10.1016/j.resconrec.2022.106176