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Impact of agricultural production outsourcing service and land fragmentation on agricultural non-point source pollution in China: Evidence from Jiangxi Province

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Agricultural production outsourcing service (APOS) are developing rapidly in China. In-depth research on whether the development of agricultural production outsourcing service can reduce agricultural non-point source pollution (ANSP) and the influencing mechanisms is still lacking. This study analyze the underlying mechanisms and empirically estimate the impact of agricultural production outsourcing service on agricultural non-point source pollution, explore the effect of land fragmentation on the relationship between them, and further empirically test these relationships with microsurvey data on farmers in China. The results reveal that agricultural production outsourcing service are negatively correlated with excess nitrogen and chemical fertilizer input. Agricultural production outsourcing service use can reduce excess nitrogen and an increase in the number of plots of land leads to an increase in excess nitrogen, and lower the negative effect of agricultural production outsourcing service on excess nitrogen. Agricultural production outsourcing service affect excess nitrogen by reducing farmers' input of chemical fertilizers and increasing their adoption of green agricultural production technology. In the future, China should vigorously promote the development of agricultural production outsourcing service organizations, improve the standardization of outsourcing services to expand the scale of agricultural production outsourcing service. The government should also strengthen policy support for the construction of field roads, water conservation and irrigation, and should strive to centrally manage scattered land. It is necessary to encourage small-scale farmers to outsource agricultural production activities to the service organizations, thus reducing the negative effect of land fragmentation and increasing the positive effect of agricultural production outsourcing service in reducing agricultural non-point source pollution.

KEYWORDS

agricultural production outsourcing services, excess nitrogen, land fragmentation, economics of scale, agricultural technology

1 Introduction

Agriculture is not only highly dependent on the ecological environment but also impacts it. The input of agricultural factors has negative environmental externalities. As one of the most prominent sources of water pollution, agricultural non-point source pollution (hereinafter referred to as ANSP) has become increasingly serious (Abler, 2015; Zhang et al., 2018; Zhou, et al., 2021). Over the past 30–40 years, ANSP has been severe worldwide due to the overuse of chemical fertilizers (Carpenter et al., 1998; Li et al., 2019). Agriculture is the largest source of chemical oxygen demand (COD) and the second largest source of ammonia nitrogen in water pollution (Ministry of Ecology and Environment of the People's Republic of China, 2020). Yu et al. (2020) revealed that the scale of China's agriculture is showing a trend of rapid development, and it is important to note that agricultural environmental pollution cannot be ignored. Chinese crop yields have increased for 17 consecutive years since 2004, and total crop yields have exceeded 650 billion kilograms for 6 consecutive years. China feeds 22% of the world's population with only 10% of the world's arable land. However, extensive agricultural management with high levels of input and high levels of pollution leads to low agriculture utilization rates. Data released by the Ministry of Agriculture and Rural Affairs of China show that the utilization rate of chemical fertilizers for rice, wheat and corn in China was only 40.2%, and the utilization rate of pesticides was 40.6% in 2020. ANSP has become one of the most complicated and challenging issues related to environmental protection in China. Reducing the application of agricultural inputs and increasing their utilization rate have been widely adopted to govern ANSP worldwide. To eliminate the sources of ANSP in the agricultural sector, such as the inefficient utilization of production factors, the Chinese government has implemented a series of measures. The No. 1 Document of the Central Committee of the Communist Party of China (CCCPC) explicitly proposed strengthening ANSP prevention in 2004. In the following 18 years, policies have been proposed to deal with ANSP in rural areas. In addition, in its 14th Five-Year Plan for the Green Development of Agriculture, China set unequivocal quantitative targets to increase the utilization rate of chemical fertilizer to 43% (State Council of the People's Republic of China, 2021a). In 2022, the No. 1 Document of the CCCPC proposed "strengthening the comprehensive treatment of ANSP and further reducing the amount of agricultural input".

Chinese urbanization is accelerating, and the agricultural labor force will inevitably transfer to urban non-agricultural sectors. The high rate of agricultural labor transfer has worsened the aging of the agricultural labor force and increased the number of women involved in farming, while the overall supply of agricultural labor is decreasing. This has had an adverse impact on ANSP. Agricultural production outsourcing service (APOS) organizations in China have the advantage of utilizing advanced agricultural technology, modern equipment and management ideas. By outsourcing part or all of the steps of agricultural production to APOS organizations, farmers can compensate for the shortage of agricultural labor and the lack of advanced agricultural technology and equipment, theoretically improving the utilization rate of chemical fertilizers in agriculture and reducing ANSP. The 14th Five-Year Plan for the Green Development of Agriculture in China points out that "support a number of professional agricultural outsourcing service organizations to strengthen the prevention and treatment of ANSP" (State Council of the People's Republic of China, 2021b). The 14th Five-Year Plan for Modernizing Rural Agriculture in China also makes it a priority to "develop APOS organizations and introduce advanced agricultural varieties, inputs, technologies and equipment to small-scale farmers" (State Council of the People's Republic of China, 2021a). Data released by the Ministry of Agriculture and Rural Affairs of China show that by the end of 2020, the total number of APOS organizations in China exceeded 950,000, servicing 110 million ha of farmland and 78 million small-scale. APOS are the major driving force behind the reduction in chemical fertilizer use in China, and studying the effect of APOS on ANSP is of great theoretical and practical value for reducing ANSP.

APOS are effective because they reduce the agricultural cost per unit of area through the development of a large-scale service area. That is how the supply cost advantage of APOS is formed. China's cultivated land area is highly fragmented and generally managed through small-scale farming. At present, the pattern of managing fragmented land has not changed; rather, land fragmentation has increased in China, where the *per capita* area of cultivated land is only .1 ha, the mean farm size is approximately .6 ha, and the number of plots per household is 5. There are still 210 million farmers with farms smaller than .6 ha. China has a large agricultural population, and farmers still engage in agricultural production on fragmented farmland. This raises the question of whether land fragmentation places external constraints on the growth of the area served by APOS organizations and affects ANSP. Poyang Lake is the largest freshwater lake in China. It is also an important ecological protection area in China and a global important ecological area designated by the World Wide Fund for Nature. Data released by water resources department of Jiangxi Province showed that ANSP contributed 69% of total nitrogen, 81.6% of total phosphorus and 55.2% of chemical oxygen demand to the pollution in Poyang Lake. How to effectively solve the problem of ANSP in Poyang Lake Basin is urgent. The whole area of Poyang Lake is in Jiangxi Province, China. Therefore, the object of this study is to analyze the underlying mechanisms and empirically estimate the impact of APOS on ANSP, explore the effect of land fragmentation on the relationship between them, and further empirically test these relationships with microsurvey data on farmers in Jiangxi Province.

Many scholars have studied the impact of APOS on agricultural production and the differences in farmer demand for outsourcing services in agricultural production, with very valuable results having been obtained. However, few studies have directly discussed the effect of APOS on ANSP, and even fewer have empirically analyzed the mechanism underlying this relationship. Sun et al. (2019) found that farmers have a greater demand for outsourcing services related to farmland preparation and harvesting but less demand for outsourcing services related to fertilization and pesticide application. Farm size (Massayo et al., 2008), age, gender, education level, social network strength, non-agricultural income and other household characteristics have different degrees of influence on APOS use (Gebregziabher, 2015; Materia et al., 2017; Zhang et al., 2017; Baiyegunhi et al., 2019). Most studies have found that APOS are effective replacements for household labor and reduce agricultural labor costs (Gooroochum and Hanley, 2007), increase the income of farmers (Lyne et al., 2018; Mi et al., 2020), improve agricultural technical efficiency (Bangkim et al., 2021), reduce farmland abandonment (Luo et al., 2019) and promote increases in the scale of the farmland under management (Kang et al., 2020). With the development of research, some scholars have begun to directly study the impact of APOS on the relationship between agriculture and the environment. Ying and Xu (2017) found that outsourcing fertilization can significantly reduce the intensity of fertilizer application, especially among small-scale farmers. Ji (2018) argued that APOS significantly reduce the use of pesticides, increasing the prevention and control of pesticide misuse and ensuring the scientific use of pesticides. Cai et al. (2019) found that joining an agricultural cooperative increased the probability of family farms reducing their chemical fertilizer and pesticide use by 43.3% and 43.7%, respectively. Zhang and Luo (2020) found that the more farmers used APOS, the stronger the positive effect of increased land plot size and farm size on chemical fertilizer application. Lu et al. (2021) found that farmers' purchases of APOS significantly increased their adoption of environmentally friendly agricultural technology. Tian et al. (2019) concluded that agricultural mechanization services can change the way that farmers use polluting input factors and dispose of agricultural production waste, which is beneficial to the ecological environment. Li et al. (2021) found that the more that farmers adopt outsourcing services for green agricultural production, the higher their green agricultural productivity. However, that study used a comprehensive index to describe the agricultural environment and lacked a detailed analysis of ANSP.

Transportation, manufacturing and construction industry pollution has always attracted the most attention among scholars (Jiang et al., 2022), and ANSP, which is dispersed and more difficult to control, has been neglected. Whether APOS can effectively reduce ANSP is of great importance for the green development of Chinese agriculture. Unfortunately, there has been no in-depth analysis of this topic. As a result, the main contribution of the paper is that it provides empirical evidence on how APOS can increase optimal use of chemical fertilizers and reduce negative environmental impact. In addition, it identified the implication of land fragmentation on the relationship between APOS and the use of excessive nitrogen. The rest of this paper is organized as follows. Section 2 presents the mechanism analysis and model construction. In Section 3, the data sources and variables used are described. Section 4 presents an analysis of the empirical results, the robustness checks and the mechanism test. The conclusion and discussions are reported in Section 5.

2 Mechanism analysis and model construction

2.1 Mechanism analysis

APOS are not only effective replacements for agricultural laborers, but they also provide advanced agricultural technology, modern equipment and information advantages that farmers do not have, which substantially improves factor utilization rates, increasing the use of environmentally friendly factors and reducing ANSP. APOS organizations can prepare farmland, sow, transplant, fertilize and apply pesticide for farmers. As the opportunity cost of farming continues to rise, the constraint of labor on agricultural production increases. As a substitute for the labor force, the agricultural mechanization services provided by APOS organizations can alleviate the labor constraints faced by farmers and encourage them to lease land (Yang et al., 2019). Agricultural machinery assets are highly specific, and APOS organizations make it easy for farmers to obtain agricultural machinery services, saving them the substantial amount of funds needed to buy such assets by themselves. The development and application of agricultural science and technology has become the key to the development of modern agriculture, but most farmers (especially large-scale farmers), constrained by the limited resources of public agricultural technology extensions, cannot directly obtain technical support. APOS organizations can introduce advanced agricultural techniques and equipment into agricultural production, alleviate the technical constraints faced by farmers, and increase the scale of farmland under management. This results in the optimization of input factors and a reduction in the amount of chemical fertilizer input per unit of area (Lu et al., 2019).

Individual farmers often face problems such as financial barriers, farm size thresholds and technical risks when adopting green agricultural production technology. This not only reduces farmers' trust in green production technology but also makes it difficult for farmers who are willing to adopt these techniques to take action. After outsourcing agricultural production to APOS organizations, farmers can rely on their advantages in terms of professional and technical personnel, modern agricultural technology and modern equipment to alleviate the high risk and high cost of technology adoption (Ma et al., 2018). APOS can replace the use of some agricultural chemicals in production to an extent and thus alleviate the ANSP caused by the overuse of such chemicals. In addition, APOS organizations can also cause farmers who are not willing to adopt green agricultural production technologies to use these techniques, change the composition of their agricultural inputs, and reduce ANSP by providing large-scale farmland management and vertical multilink services related to agricultural production.

The immobility of land and the different terrain and areas of land plots all affect the scope, scale, and frequency of service provision by APOS organizations as well as the input and allocation of labor, capital and other factors by farmers. Recently, agricultural labor costs in China have been increasing. Given that the average farm size is small and agricultural machinery suitable for small plots of land is not widely used, land fragmentation hinders the development of the APOS market, generating extremely large costs to coordinate between farmers and APOS organizations. These costs restrict the expansion of the scale of APOS. In addition, APOS organizations also choose to provide their services on relatively flat plots of land, for the cost of service supply is relatively low due to cost and income considerations. Finally, agricultural production requirements include farming, and the natural growth cycles of crops result in the concentration of production times within a few days. APOS organizations may seek to increase the number of times when they provide services and their service area, resulting in a high probability of moral hazard. Land fragmentation may increase this probability and directly affect the efficiency with which agricultural production factors are allocated (Figure 1).

2.2 Model construction

To quantitatively measure the impact of APOS on ANSP in the context of land fragmentation, the following econometric model was constructed:

$$Y = \alpha_0 + \alpha_1 OS + \alpha_2 plot + \beta X + \varepsilon \tag{1}$$

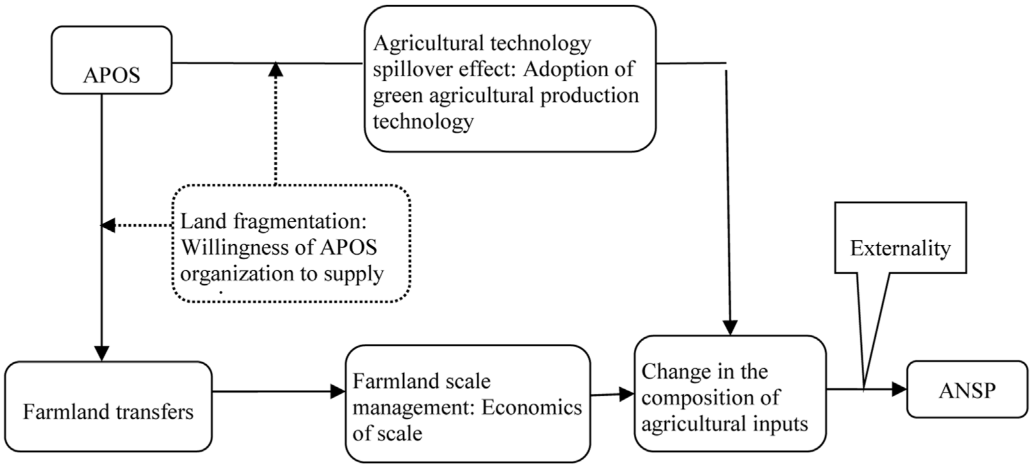

FIGURE 1
Analytical framework for the effect of APOS on ANSP.

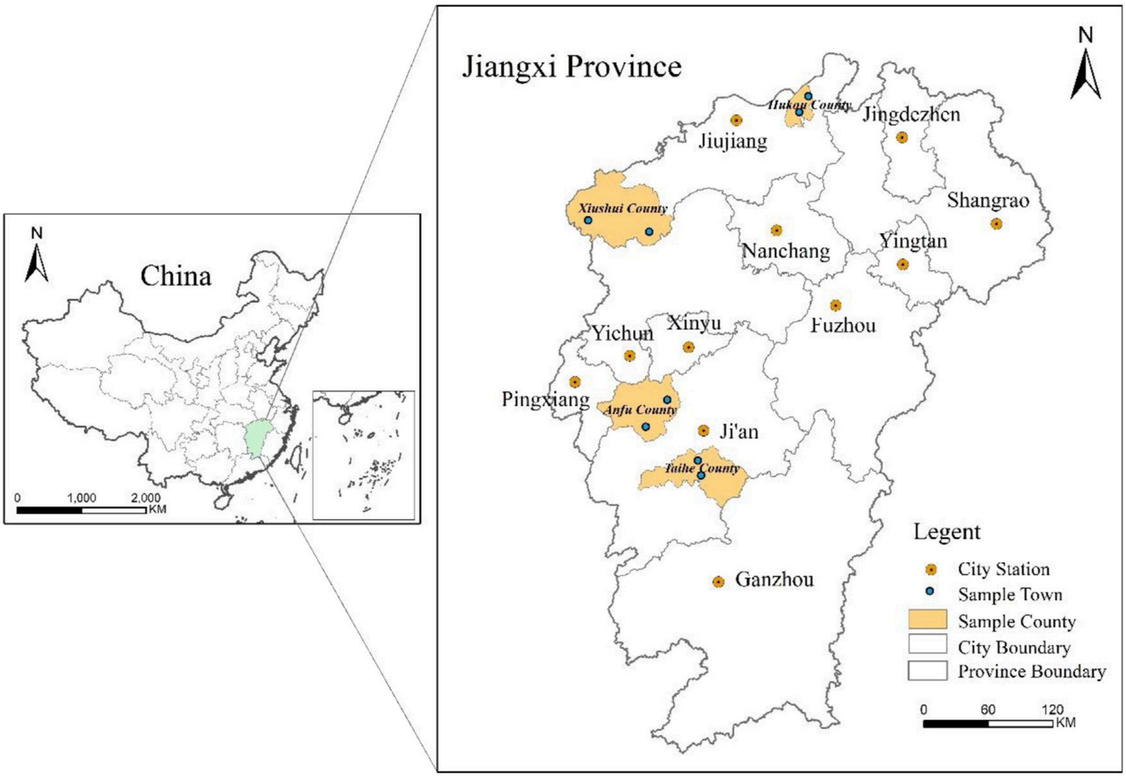

FIGURE 2
Location of Jiangxi Province in China and the study area.

where Y is the ANSP of the farmer, which is dispersed, random, and difficult to monitor and quantify. OS indicates the extent to which the farmer outsources agricultural production. plot indicates the extent of land fragmentation, X_i is a vector of family characteristic variables and of land characteristic variables, and ε is a random disturbance term.

To further investigate the influence of APOS on ANSP in the context of land fragmentation, we follow Zhong et al. (2016) and Lu et al. (2019) and add an interaction term between the number of plots of land and the extent of APOS use to Eq. 1. The sign and significance of the coefficient on the interaction term α_3 indicates the influence of

APOSs on ANSP under different degrees of land fragmentation. The model is as follows:

$$Y = \alpha_0 + \alpha_1 OS + \alpha_2 plot + \alpha_3 \times OS \times plot + \beta X + \varepsilon \tag{2}$$

3 Data source and variable selection

3.1 Data source

This study examines rice growers in Jiangxi Province (Figure 2) for the following two reasons. First, at present, APOS are mainly used in the production of food crops, and related research on food crops can better identify the development status of APOS and their problems. Second, rice is one of the most important food crops in China. As an important commodity grain base in China, Jiangxi Province is one of two provinces that have provided commodity grains to the country continuously since the founding of the People's Republic of China. Jiangxi Province is a major grain-producing area located in southeastern China. The total area of cultivated land in the province is 3.08 × 104 km^2, accounting for 18.48% of the total cultivated land area in China. ANSP is a serious problem in Jiangxi Province, and the government has adopted many stringent ANSP control measures and other policies. In addition, APOS are prevalent in Jiangxi Province, as is well known throughout the country. Therefore, while this study is based on this particular area, it has important reference value for Chinese control of ANSP.

The data used in this paper come from the survey "APOS and Rice Production", carried out by the research group in Jiangxi Province in 2021. There are great differences in regional economic development and geomorphological features across Jiangxi Province. Based on a comprehensive consideration of the baseline level of agriculture in the various regions, Jiujiang city in the north of Jiangxi Province, Ji'an city in the middle were selected as sample areas, with respondents selected through stratified random sampling. Two county was randomly selected from each city, two towns were randomly selected from each county, and four villages were randomly selected from each town, with 10–15 households selected from each village.

Given the research focus of this study, the questionnaire collected the following information: 1) family characteristics, such as the age of the head of the household, his or her education level, the number of workers in the family, whether any household members are village cadres, and the employment status of family members; 2) details on the cultivated land, such as the total area of cultivated land, the number of land plots, the quality of the cultivated land, and whether any farmland had been transferred; 3) the input of factors, such as chemical fertilizers and pesticides, among others, and the use of APOS at different steps in the agricultural production process; 4) the adoption of green production technology, such as organic fertilizers and biological pesticides, by farmers. To ensure the quality of the survey, before the formal investigation, the researchers conducted several intensive trainings with the interviewers, explained the relevant content on the questionnaire, and clarified the meaning of relevant topics. The formal investigation was conducted through face-to-face interactions between an investigator and the farmers, and the investigator completed the questionnaires on behalf of the farmers. This method prevented any misunderstandings that could have arisen if the farmers had completed the questionnaires themselves. After the survey was completed, the questionnaires were examined, cross-checked and compiled. A total of 324 valid questionnaires were obtained.

3.2 Variable selection

(1) Dependent variable. The overuse of chemical fertilizers is an important cause of ANSP in China (National Bureau of Statistics, 2010). The Second Pollution Source Census of China reported that in 2017, the total nitrogen loss from crop farming was 719,500 tons. Drawing on Truog's nutrient balance theory, this study uses the "excess nitrogen"[1] index for agriculturalproduction to quantitatively measure ANSP. Excess nitrogen is the difference between the amount of nitrogen input and the amount required by the crop according to nutrient balance theory. The formula for calculating this excess nitrogen ($Excess\_N$) is as follows:

$$Excess\_N = total\_N - need\_N \tag{3}$$

where $total\_N$ represents the nitrogen introduced by farmers using chemical fertilizers, and $need\_N$ represents the nutrients required for the crops to achieve normal economic yields[2]. It should be noted that the intent of this study is not to accurately measure the total amount of excess nitrogen in agricultural production but only to analyze the behavior of farmers in the context of agricultural labor transfers. Livestock production is mainly affected by the amount of capital available, and the nitrogen emissions from manure are not included in the calculation; furthermore, the nitrogen contributed by the baseline fertility of the soil, agricultural films and irrigation water are not taken into account due to data limitations.

(2) Core explanatory variables. In this study, the outsourcing service fee per ha is used to measure the extent to which farmers outsource their agricultural production. APOS are available for five steps in the agricultural production process: farmland preparation, rice transplanting, fertilization, pesticide application, and harvesting. The number of land plots indicates the level of land fragmentation.

(3) Other control variables. Family characteristics are an important factor affecting the agricultural production behaviors of farmers. According to the theory of farmer behavior and following existing studies (Lu et al., 2022), the age, gender, education level, farming level and non-agricultural training of the household heads are used to measure household characteristics in this study.

1 "Excess nitrogen" is the difference between the nitrogen input and the amount of nitrogen required by the crop according to nutrient balance theory.

2 These data come from the agricultural economic manual. The nitrogen content per 100 kg of rice yield is 2.05 kg.

TABLE 1 Descriptive statistics.

Variable	Definition and unit	Mean	S.D.
Excess nitrogen	The amount of nitrogen input minus the amount of nitrogen required as a crop nutrient (kg/ha)	33.26	61.87
Services fee	Agricultural outsourcing service fee (yuan/ha)	2,958.47	1,371
Number of plots	Number	12.61	16.31
Farmland size	Total ha	1.41	4.90
Price	Retail price of rice (yuan/kg)	.65	.09
Quality	Can high-quality products receive a high price? 1 = Absolutely not; 2 = Unlikely; 3 = Uncertain; 4 = Could be possible; 5 = Entirely possible)	3.35	1.10
Gender	Gender of head of household (0 = female, 1 = male)	.95	.22
Age	Age of head of the household (age)	57.92	9.29
Education	Education of head of the household (years)	2.60	.93
Leader	Leader at the village level in the family (0 = no, 1 = yes)	.29	.46
Train	Has the head of the farming household received training in agricultural technology? (0 = no, 1 = yes)	.50	.50
Farming status	Farming status of the head of household (0 = unable to work; 1 = Only farming; 2 = Farming is the main occupation; 3 = Non-farm work is the main occupation; 4 = Only non-farm work)	1.69	.80
Degree of technology adoption	The extent of farmers' adoption of green agricultural production technology*	.39	.19

4 Results

4.1 Statistical analysis

Table 1 presents the definition and descriptive statistics for each variable. In general, excessive nitrogen is very common in the sample area, with an average of 33.26 kg of excess nitrogen per ha, which further suggests that in China, the application of fertilizer is excessive. This finding is consistent with the conclusions drawn by Qiu et al. (2014), who stated that the application of fertilizer per unit of cultivated land in China has far exceeded both the global average and the optimal amount and that it continues to follow a clear upward trend. The average APOS fee is 2,958 yuan per ha. According to the survey results, there is a great deal of variation in the outsourcing of activities at the different steps of the agricultural production process. The vast majority of farmers outsource farmland preparation and harvesting to APOS organizations, accounting for 57% and 90% of surveyed farmers respectively. However, only 7% of surveyed farmers outsource fertilization and application to APOS organizations. The average retail price for rice is .65 yuan per kg, but farmers generally believe that high-quality agricultural products can receive high prices. The average area of the land under cultivation is 1.41 ha, and the average number of plots is 12.61. Land fragmentation is severe and indicates that most farmers are small-scale and manage fragmented land. In terms of personal characteristics, approximately 95% of the heads of farming households in the sample area are male, with an average age of 57.92 years old. Their main work is agricultural production, and their education level is low, with an average attainment below junior high school. China's agricultural workers are characterized by aging and part-time employment. A total of 29% of families have a member who is a leader at the village level. These leaders promotes agricultural environmental policies, and families with a leader have a much better understanding of environmental pollution. Half of the farmers have received training in agricultural techniques. Most of the farmers have not adopted green agricultural production technology, as they are in pursuit of stable output and minimum risk.

Note: 1) Author's calculations based on the survey data. 2) * In this study, the extent to which green agricultural production technology has been adopted is measured as a weighted average of farmers' use of certain technologies. In total, there are five green agricultural production technologies, namely, subsoiling, organic fertilizer, green manure, biological pesticide, and crop straw incorporation. Given that each technology is equally important, the weights are all equal to 1/5. The formula for calculating the index is $A_i = \sum \beta_j{}^* \delta_{ij}$, where A_i represents the level of green agricultural technology adoption and takes on a value in the range $[0, 1]$. $\beta_j = 1/5$, and $\delta_{ij} = 0$ or 1.

The differences in the levels of the agricultural attributes and individual heterogeneity jointly determine the degree to which farmers outsource their agricultural production. Table 2 shows that the outsourcing of agricultural production is negatively correlated with the input of excess nitrogen, compound fertilizers and carbamide; that is, excess nitrogen, compound fertilizers and carbamide in agricultural production all decrease with an increase in the outsourcing of agricultural production. Crops need to be fertilized several times during a crop growth cycle, and the concentration and composition of each application are different, which makes it difficult for fertilization to be mechanized and standardized; thus, fertilization requires a large amount of labor input. The time-sensitivity of agricultural production reduces the flexibility of agricultural labor input, leading to an increase in the labor constraints on agricultural production. APOS organizations can apply chemical fertilizers for farmers, and their professional and technical personnel can also accurately determine the correct among of chemical fertilizers to apply, thus reducing excessive

TABLE 2 Outsourcing, land fragmentation and excess nitrogen (Unit: kg/ha).

Dependent variable	Classification	Excess nitrogen	Compound fertilizers	Carbamide
Level of outsourcing services	0	75.96	803.13	156.25
	0.2	61.91	785.20	166.11
	0.4	20.30	745.64	131.39
	0.6	−28.68	696.43	117.86
	0.8	−71.68	628.13	103.13
	1	−29.98	585.00	115.50
Number of land plots	1–3	17.47	712.76	126.95
	3–5	27.55	710.35	145.57
	5–10	34.56	781.94	142.5
	≥10	44.75	784.16	152.77

Note: Author's calculations based on the survey data.

application. Moreover, APOS organizations can also rely on their own green production factors to cause farmers to adopt green production means and reduce the input of compound fertilizers and carbamide. An increase in the number of plots of land leads to an increase in the input of excess nitrogen, compound fertilizers and carbamide in agricultural production. In China, more land plots mean smaller plots, a less efficient use of modern agricultural machinery, and longer travel times between land plots. To reduce the input of labor, farmers tend to reduce the frequency with which they apply compound fertilizers and carbamide and increase the amount used in each application so as to compensate for the adverse impact of labor shortages and the inefficiency of agricultural machinery in applying fertilizer, resulting in an increase in excess nitrogen.

4.2 Empirical analysis

4.2.1 The impact of agricultural production outsourcing service and land fragmentation on agricultural non-point source pollution

Stata 15.0 software was used to quantitatively estimate the impact of APOS and land fragmentation on excess nitrogen (Table 3). The Wald test statistic for the two models is significant at the 1% level, indicating that the estimated results of the model are good overall and that the model has strong explanatory power. The average variance inflation factor (VIF) values for model 1 and model 2 were 1.28 and 3.85, respectively, indicating that there is no multicollinearity in the model. The Breusch–Pagan test results indicate that the assumption of homoscedasticity can be rejected and are significant at the 1% and 10% levels, respectively. Therefore, a weighted least squares (WLS) model is used to estimate the regression in order to obtain a consistent estimator.

The column labeled Model 1 in Table 3 presents the regression results without controlling for the number of land plots or its interaction with APOS. The impact of APOS on excess nitrogen is significantly negative at the 5% level; i.e., the more farmers outsource their agricultural production activities, the lower their excess nitrogen is. APOS organizations can complete different agricultural production steps, such as farmland preparation, sowing, rice transplanting, fertilization and pesticide application, for farmers. By outsourcing agricultural production activities to APOS organizations, farmers can directly reduce the cost of purchasing agricultural machinery independently and the labor needed to operate such machinery. Moreover, APOS organizations can purchase environmentally friendly agricultural production factors and are able to rely on their technical personnel and modern agricultural equipment to shift farmers away from excessive factor inputs, reduce negative externalities and reduce excess nitrogen. This conclusion is the same as the conclusion of Yang et al. (2020). He also founded that APOS has a significant negative effect on the input of pesticides and fertilizers, and with the deepening of APOS, the lower the level of the input of pesticides and fertilizers. The impact of the number of land plots on excess nitrogen is significantly positive at the 1% level. At present, agricultural benefits of managing fragmented land are declining, and farmers' enthusiasm for agricultural production is also declining. Chemical fertilizers need to be applied several times during a crop cycle. To reduce labor costs, it is optimal for farmers to reduce the number of times that they apply fertilizer and increase the amount of fertilizer applied each time, resulting in an increase in excess nitrogen.

The column labeled Model 2 presents the regression results regarding increases in the number of land plots and its interaction term with APOS. The coefficient on the cross term is significantly positive, indicating that an increase in the number of plots of land reduce the negative effect of APOS on excess nitrogen. This result is also the same as the conclusion of Liu et al. (2019), that is, whether APOS can be effectively supplied and have an influence on agricultural green production will be constrained by farmers' farmland size. Land fragmentation increases the cost of supplying APOS, which hinders the expansion of the outsourcing service area and reduces the negative effect of APOS on ANSP. The immobility of land and the different terrain and areas of individual plots all affect the cost, scope, area and frequency of service provision by APOS organizations: APOS organizations may choose to provide their outsourcing services to farmers with larger-scale farmland, where economies of scale can be obtained. Zhang and Luo (2020) found that the higher the degree of APOS of farmers, the stronger the promotion effect of land plot size and farmland scale on reducing fertilizer application.

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TABLE 3 Effects of land fragmentation and APOS use on excess nitrogen.

Variable	Model 1	Model 2
	Benchmark regression	Cross-term regression
APOS	.017**	.056***
	(.008)	(.010)
Number of plots	.065***	.200
	(.020)	(.145)
APOS×Number of plots	--	.003*
	--	(.001)
Price	2.810**	1.061
	(1.413)	(1.249)
Quality	.771***	.803***
	(.231)	(.247)
Farmland area	.006	.004
	(.005)	(.005)
Technology	4.975***	3.464***
	(1.486)	(1.229)
Gender	2.959**	.785
	(1.272)	(1.785)
Age	.112***	.152***
	(.025)	(.023)
Education	.384	.359
	(.324)	(.256)
Leader	.378	2.104***
	(.653)	(.563)
Training	2.129***	2.028***
	(.521)	(.522)
Farming status	.350	1.331***
	(.365)	(.357)
Constant	1.294	7.844**
	(2.759)	(3.034)
Observations	155	312
R-squared	.404	.091

Note: 1) *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively, here and in all following tables. 2) Robust standard errors are in parentheses.

The impact of the price of rice on excess nitrogen in agricultural production is significantly positive. Price affects farmers' enthusiasm for agricultural production. Rice planting is susceptible to weather and other aspects of nature, resulting in highly uncertain yields and strong risk avoidance among farmers. For elderly farmers in hilly and mountainous areas who are pursuing maximum yields, additional applications of chemical fertilizers are an important means of avoiding risk, resulting in excessive fertilization and aggravated ANSP. The impact of expecting a high price for high-quality agricultural products on excess nitrogen was negative. When farmers generally believe that high-quality agricultural products will receive a better price, it becomes rational to apply less chemical fertilizer or use organic fertilizer. As the composition of consumption among China's urban and rural residents improves and the supply-side structural reform of agriculture intensifies, consumer demand for high-quality agricultural products will continue to increase. Agricultural policy in China has also shifted from a focus on yield increases to quality improvements. The agricultural production by farmers is expected to gradually shift from a pursuit of increased yields to a pursuit of higher quality and safer products to meet consumer demand and to maximize

TABLE 4 Effects of land fragmentation and APOS use on excess nitrogen (substitution of explanatory variable).

Variable	Outsourcing of agricultural production in town		Outsourcing of agricultural production in county	
	Model 3	Model 4	Model 5	Model 6
APOS	.034***	.120***	.097***	.121***
	(.012)	(.017)	(.017)	(.035)
Number of plots	.067***	.688***	.044***	.049
	(.021)	(.175)	(.016)	(.225)
APOS× Number of plots	--	.007***	--	.001
	--	(.002)	--	(.002)
Control variables	Yes	Yes	Yes	Yes

long-term agricultural benefits. Lu et al. (2019) also believed that the ultimate goal of agricultural production is to pursue maximum agricultural returns, and the pursuit of quality will become a priority for agricultural production when the market can achieve good quality and good prices for agricultural products. Green production technology plays a significant role in reducing excess nitrogen. The use of green agricultural production technology can somewhat reduce the input of traditional chemical fertilizer and excess nitrogen to a certain extent. The influence of agricultural training on excess nitrogen is significantly negative. Agricultural training is an important method for increasing farmers' scientific knowledge about fertilization and encouraging them to adopt environmentally friendly agricultural production, thus reducing ANSP. Agricultural production needs vast farmland, and production cycles require continual outdoor work, which requires corresponding physical support. The tendency of farmers to use more chemical fertilizers in order to alleviate physical limitations increases with age. Leaders, as the implementers of policy in China, have a stronger awareness of ANSP, and households with village-level leaders have less excess nitrogen in their agricultural production. In addition, farmers' emotional attachment to their farmland decreases with an increase in non-agricultural employment, causing them to rely more on traditional chemical fertilizers.

4.2.2 Robustness analysis

To test the robustness and reliability of the estimation results, the use of APOS in the town and county where the farmers live is used as a proxy variable in the empirical analysis. The extent to which agricultural production is outsourced in the town and county mainly depends on the external market. In terms of grain production, APOS have positive externalities, and the use of APOS within the town and county can influence whether farmers outsource their agricultural production by demonstrating their effects; thus, this variable satisfies the relevancy requirement. Therefore, the use of APOS in the town and county where the farmer lives can be tested as a proxy variable for the use of agricultural production outsourcing by farmers.

Table 4 shows that the more agricultural production is outsourced in the town and county, the lower the excess nitrogen is. This conclusion is consistent with the estimation results for Model 1 and Model 2 in Table 3. The cross-term coefficient between the use of APOSs in the town and the number of land plots is significantly positive, indicating that land fragmentation reduces the negative effect of APOSs on excess nitrogen, which is consistent with the estimation results from Model 2 in Table 3 and further verifies their robustness. The coefficient on the cross-term between the use of APOSs in the county and the number of land plots in the county is insignificant. One possible reason is that the use of APOSs in the county does not demonstrate their effectiveness to village-level farmers. According to the survey, there are great differences in the planting structures and topography of the different villages, which leads to great differences in the ability of APOS use at the county level to demonstrate the effectiveness of outsourcing in the different villages.

4.2.3 Mechanism analysis

According to the analytical framework for this study, given the limited amount of labor, modern agricultural equipment and technology, farmers outsource part of their agricultural production activities to APOS organizations to relieve the constraints on labor, capital and technology in their agricultural production. APOS affect land transfers among farmers and reduce the amount of compound fertilizers and carbamide per ha through changes in the scale of farmland under management. In addition, APOS organization can also drive farmers to adopt green agricultural production technologies and reduce the ANSP caused by traditional chemical fertilizer application. Therefore, this study tests whether the amount of compound fertilizers and carbamide used per unit ha and farmers' adoption of green agricultural production technology are mechanisms underlying the observed relationship between APOS use and excess nitrogen.

The results in the columns labeled Model 7 and Model 8 in Table 5 show that the effect of APOS on the amount of compound fertilizers and carbamide used per ha is significantly negative. APOS reduces farmers' input of chemical fertilizer, and with an increase in APOS use, the input of chemical fertilizers decreases. Relying on their professional and technical personnel and modern agricultural equipment, APOS organizations can master the effect of fertilization given different timings for fertilization and can provide farmers with more targeted fertilization applications and frequencies, thus improving the effect of fertilization and reducing the amount of compound fertilizers and carbamide used per ha. In addition, APOS organizations can screen and use different chemical fertilizers and can also improve the efficiency of fertilization and reduce excess nitrogen by reducing excessive applications of fertilizer. The results presented

TABLE 5 Analysis of the mechanisms underlying the effect of APOS use on ANSP.

Variable	Model 7	Model 8	Model 9
	Amount of compound fertilizers	Amount of carbamide	Adoption of green agricultural production technology
APOS	.028*	.020***	.0003***
	(.014)	(.008)	(.0001)
Number of plots	.023	.031	.002***
	(.103)	(.033)	(.001)
Control variables	Yes	Yes	Yes
Observations	324	324	324
R-squared	.081	.104	.154

in the column labeled Model 9 show that APOS use significantly increases the adoption of green agricultural production technology among farmers, which is consistent with the findings of Lewis and Pattinasarany (2009), and this paper believed that APOS can promote farmers to adopt environment-friendly technologies and reduce chemical fertilizer application.

5 Conclusion and implications

ANSP, which is primarily caused by fertilizer runoff from farmland, has led to many concerns. APOS use is an important form of agricultural production in China, and this study examines whether APOS use has effectively reduced ANSP. Using the microsurvey data on farmers in Jiangxi Province, China, this paper is the first published paper to answer the following questions: 1) Does APOS use reduce excess nitrogen? 2) Does land fragmentation play a role in reducing the positive impacts of APOS use on ANSP? This study develops an econometric model and statistically analyzes the impact of APOS use and land fragmentation on excess nitrogen. The evidence presented in this paper points to an important relationship: excess nitrogen and the input of compound fertilizers and carbamide in agricultural production all decrease with an increase in the ANSP. We also find that APOS use can significantly reduce excess nitrogen in agricultural production. Land fragmentation leads to increased excess nitrogen and reduces the negative effect of APOS on excess nitrogen. In addition, APOS affects excess nitrogen by reducing the input of chemical fertilizer and promoting farmers' adoption of green agricultural production techniques. This paper scientifically identified the implication of land fragmentation on the relationship between APOS and the use of excessive nitrogen. It is a marginal contribution to the existing research on ANSP in China.

These findings have important implications for future ANSP control in China. First, the government should increase the policy support for APOS and thereby strengthen the role of APOS in reducing ANSP. It is necessary to strengthen the supervision of contracts between APOS organizations and farmers and to improve the standardization of outsourcing service activities. Moreover, it is also necessary to improve farmers' enthusiasm for outsourcing the production activities in agriculture, and to ultimately reduce ANSP. Given the heterogeneity in the different activities of agricultural production, policies meant to support different AOS should be different. Service behaviors should be standardized for those steps that require relatively intensive technology use, such as chemical fertilizer and pesticide application, so as to encourage farmers to outsource more of agricultural production activities to APOS organizations. Second, large agricultural machinery are difficult to operate independently on scattered and fragmented land. The government should strengthen policy support for the construction of field roads, water conservation and irrigation, and other land infrastructure and should strive to centrally manage scattered land, so as to reduce the constraints imposed by land fragmentation and increase the positive role of APOS use in reducing ANSP. Third, China cannot ignore the important role of farmland scale management in the modernization of its agricultural production and should continue to focus on standardizing the market for the farmland transfer, reducing farmland transfer costs, and coordinating the balanced development of farmland scale management and APOS. Fourth, the government should give more guidance to the collective actions of farmers in agricultural production and ensure that the same crop varieties are planted on contiguous plots so that the scale of APOS can increase. APOS organizations can unite small-scale farmers who do not participate in farmland transfers by not changing the contracted rights of farmers. Therefore, we should focus on the production needs of small-scale farmers and improve their awareness of collective action in agriculture, create favorable conditions for expanding the scale of APOS and thus reduce ANSP.

There are also some limitations to this study. APOS organizations with different forms of contracts, such as single-step contracts, multistep contracts, whole-process production trusteeships, and other service organization models, have different goals and organizational forms such as "APOS organizations + new types of agricultural businesses + farmers". Outsourcing service mechanisms such as agricultural production factor services and agricultural technology services may have different impacts on ANSP. Limited by the quality of the survey data, the problems of APOS organizations with different forms of contracts are not analyzed in this study but should be brought into the analytical framework for APOS studies and further discussed in the future to help the research conclusions and relevant policies be more targeted.

Data availability statement

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author.

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

HL had the original idea and data collecting, SC and ZZ carried out the analyses for the study, the authors drafted the manuscript and the approved the manuscript.

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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

Abler, D. (2015). Economic evaluation of agricultural pollution control options for China. *J. Integr. Agric.* 14, 1045–1056. doi:10.1016/S2095-3119(14)60988-6

Baiyegunhi, L. J. S., Majokweni, Z. P., and Ferrer, S. R. D. (2019). Impact of outsourced agricultural Extension program on Smallholder farmers' net farm income in Msinga, KwaZulu-Natal, South Africa. *Technol. Soc.* 57, 1–7. doi:10.1016/j.techsoc.2018.11.003

Bangkim, B., Mallick, B., Roy, A., and Sultana, Z. (2021). Impact of agriculture extension services on technical efficiency of rural paddy farmers in southwest Bangladesh. *Environ. Challenges* 5, 100261. doi:10.1016/j.envc.2021.100261

Cai, R., Wang, Z. Y., and Du, Z. X. (2019). Is the demonstration family farm technology more efficient? *Chin. Rural. Econ.* 3, 65–81.

Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., and Smith, V. H. (1998). Non-point pollution of surface waters with phosphorus and nitrogen. *Issue. Ecolo* 8 (3), 559–568.

Gebregziabher, K. (2015). The impact of agricultural extension on households' welfare in Ethiopia. *Int. J. Soc. Stud. Econ.* 42 (8), 733–748. doi:10.1108/IJSE-05-2014-0088

Gooroochurn, N., and Hanley, A. (2007). A tale of two literatures: Transaction costs and property rights in innovation outsourcing. *Res. Policy* 36 (10), 1483–1495. doi:10.1016/j.respol.2007.07.001

Ji, M. F. (2018). Agricultural producer services: The third kinetic energy in the history of China's agricultural modernization. *Issues Agric. Econ.* 3, 9–15. doi:10.13246/j.cnki.iae.2018.03.003

Jiang, T. Y., Li, S. Q., Yu, Y., and Peng, Y. Y. (2022). Energy-related carbon emissions and structural emissions reduction of China's construction industry: The perspective of input–output analysis. *Environ. Sci. Pollut. Res.* 29, 39515–39527. doi:10.1007/s11356-021-17604-1

Kang, C., Liu, J. C., and Xu, Z. G. (2020). Impact of agricultural production outsourcing service on rural land rent transfer. *Chin. Rural. Econ.* 9, 105–123.

Lewis, B. D., and Pattinasarany, D. (2009). Determining citizen satisfaction with local public education in Indonesia: The significance of actual service quality and governance conditions. *Growth Change* 40 (1), 85–115. doi:10.1111/j.1468-2257.2008.00462.x

Li, C. X., Xu, J. B., and Wang, Y. (2021). Can socialization service of agricultural green production improve agricultural green productivity? *J. Agrotech. Econ.* 9, 36–49. doi:10.13246/j.cnki.jae.2021.09.003

Li, X. P., Liu, W. X., Yan, Y., Fan, G. Y., and Zhao, M. J. (2019). Rural households' willingness to accept compensation standards for controlling agricultural non-point source pollution: A case study of the qinba water source area in northwest China. *Water* 11 (6), 1251. doi:10.3390/w11061251

Liu, J. C., Zhong, F. N., Xu, Z. G., and Qiu, H. G. (2019). Heterogeneity and causes of farmer's production link outsourcing behavior from the perspective of division of labor. *J. Agrotech. Econ.* 7, 4–14. doi:10.13246/j.cnki.jae.2019.07.001

Lu, H., Chen, Y. J., Hu, H., and Geng, X. H. (2021). Can agricultural productive services promote the adoption of environmentally friendly agricultural techniques by farmers. *J. Agrotech. Econ.* 3, 36–49. doi:10.13246/j.cnki.jae.2021.03.003

Lu, H., Chen, Y. J., Zhang, P. W., Huan, H. T., Xie, H. T., and Hu, H. (2022). Impacts of farmland size and benefit expectations on the utilization of straw resources: Evidence from crop straw incorporation in China. *Soil. use. Manag.* 38, 929–939. doi:10.1111/sum.12739

Lu, H., Zhang, P. W., Hu, H., Xie, H. L., Yu, Z. N., 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

Luo, B. L., Wan, Y. L., Hong, W. J., and Zhong, W. J. (2019). Land fragmentation, service outsourcing and farmland abandonment: An empirical analysis based on 2704 farmer questionnaires in 9 provinces. *Econ. Rev. J.* 7, 63–73. doi:10.16528/j.cnki.22-1054/f.201907063

Lyne, M. C., Jonas, N., and Ortmann, G. F. (2018). A quantitative assessment of an outsourced agricultural extension service in the Umzimkhulu district of KwaZulu-Natal, South Africa. *J. Agric. Edu. Exten.* 24 (1), 51–64. doi:10.1080/1389224x.2017.1387159

Ma, W., Abdulai, A., and Goetz, R. (2018). Agricultural cooperatives and investment in organic soil amendments and chemical fertilizer in China. *Am. J. Agric. Econ.* 100 (2), 502–520. doi:10.1093/ajae/aax079

Massayo, I., Hendriksen, A., and Heijman, W. J. M. (2008). Agricultural outsourcing: A comparison between The Netherlands and Japan. *Appl. Stud. Agribus. Commer.* 2, 1–6. doi:10.22004/ag.econ.48332

Materia, V. C., Pascucci, S., and Dries, L. (2017). Are in-house and outsourcing innovation strategies correlated? Evidence from the European agri-food sector. *J. Agric. Econ.* 68 (1), 249–268. doi:10.1111/1477-9552.12206

Mi, Q., Li, X. D., and Gao, J. Z. (2020). How to improve the welfare of smallholders through agricultural production outsourcing: Evidence from cotton farmers in xinjiang, northwest China. *J. Clean. Prod.* 256, 120636. doi:10.1016/j.jclepro.2020.120636

Ministry of Ecology and Environment of the People's Republic of China (2020). *China's environmental statistical yearbook*. Beijing: China Statistics Press.

National Bureau of Statistics (2010). *The first Pollution Source Census of China, 2010*. Beijing: China Statistics Press.

Qiu, H. G., Luan, H., Li, J., and Wang, Y. J. (2014). The impact of risk aversion on farmers' excessive fertilizer application behavior. *Chin. Rural. Econ.* 3, 85–96.

State Council of the People's Republic of China (2021b). *The 14th five-year plan for modernizing rural agriculture of China*. Beijing, China: FAO.

State Council of the People's Republic of China (2021a). *The 14th five-year plan for national agricultural green development*. Beijing, China: FAO.

Sun, D. D., Asmelash, M., Lu, Y. T., and Liu, M. X. (2019). The relationship between job quality supervision, risk preference and farmers' demand for outsourcing services. *J. Agrotech. Econ.* 4, 4–15. doi:10.13246/j.cnki.jae.2019.04.011

Tian, X. H., Li, W., and Li, R. (2019). Environmental effects of agricultural mechanization: Evidence from agricultural machinery purchase subsidy policy. *Chin. Rural. Econ.* 9, 95–109.

Yang, G. D., Zhang, L., Yue, M., and Zhang, J. B. (2020). Can agricultural socialized services promote agricultural reduced production. *World Agric.* 5, 85–95. doi:10.13856/j.cn11-1097/s.2020.05.010

Yang, Z., Rao, F. P., and Zhu, P. X. (2019). The impact of agricultural productive services on land scale management: An empirical analysis based on the perspective of farmers' land transfer. *Chin. Rural. Econ.* 3, 82–95.

Ying, R. Y., and Xu, B. (2017). Effects of specialized pest control services on pesticide application intensity. *Chin. Popul. Resour. Environ.* 8, 90–97.

Yu, Y., Jiang, T. Y., Li, S. Q., Li, X. L., and Gao, D. C. (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, L., Luo, B. L., Song, P., Liu, S., Liu, P., Liu, C., et al. (2020). Agricultural reduction: Scale logic of farmer's operation and its evidence. *Chin. Rural. Econ.* 2, 81–96. doi:10.3897/zookeys.995.58092

Zhang, X., Yang, J., and Thomas, R. (2017). Mechanization outsourcing clusters and division of labor in Chinese agriculture. *Chin. Econ. Rev.* 43, 184–195. doi:10.1016/j.chieco.2017.01.012

Zhang, X., Zhou, L., and Liu, Y. Q. (2018). Modeling land use changes and their impacts on non-point source pollution in a southeast China coastal watershed. *Int. J. Environ. Res. Public Health* 15, 1593. doi:10.3390/ijerph15081593

Zhong, F. N., Lu, W. Y., and Xu, Z. G. (2016). Is rural labor out-migrating badly for food production? Analysis of farmer factor substitution and behavior and constraint conditions of planting structure. *Chin. Rural. Econ.* 7, 36–47.

Zhou, L., Li, L. Z., and Huang, J. K. (2021). The river chief system and agricultural non-point source water pollution control in China. *J. Integr. Agri.* 20 (5), 1382–1395. doi:10.1016/S2095-3119(20)63370-6