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Hierarchical Linkage between the Basic Characteristics of Smallholders and Technology Awareness Determines Small-Holders' Willingness to Adopt Green Production Technology

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Abstract: As a collection of technologies that match the carrying capacity of resources and the environment, harmonize ecology and life, and balance the quantity and quality of agricultural products in agricultural production, green production technologies are regarded as an important means to help promote sustainable agricultural production. It includes scientific fertilization technology, water-saving irrigation technology, biological control technology, and conservation tillage technology. However, the smallholders' low level of awareness and application of green production technology has become a key factor limiting the sustainable development of Chinese agriculture. Several technological innovations have been implemented to address these problems while many studies have been conducted on the smallholders' willingness to adopt the technology. However, the correlation and the hierarchical structure among different factors are not clear. Therefore, to clarify these issues, we used the logit model and interpretative structural modeling (ISM) to analyze the factors influencing the adoption of green production technologies by smallholders and the hierarchical linkage between them based on a sample of 709 from 16 provinces in China. Our results revealed that scientific fertilization and biological control technology were most preferred by smallholders. Compared with wheat (38.8%, 43.2%) and maize (29.3%, 39.4%), rice smallholders (66.7%, 82.5%) were more willing to adopt the two technologies. In addition, the technology awareness and technology benefits were expected to significantly affect the smallholders' willingness to adopt the technology directly. Household characteristics and land characteristics are the root factors affecting the smallholders' willingness to adopt green production technology. Family characteristics and land characteristics also changed the willingness of smallholders to adopt green production technologies by changing their awareness of production technology and the technological benefits expected. Therefore, accelerating the promotion of green production technologies through the implementation of policies such as increasing the promotion of high-value-added agricultural products and cultivation techniques, increasing out-of-school knowledge education, and enhancing the construction of agricultural production infrastructure can be potentially viable ways to promote green transformation in agriculture. This study provides case support for increasing the smallholders' adoption of green production technology.

Keywords: smallholders; technology awareness; logit model; interpretative structural modeling (ISM)

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1. Introduction

With the rise in the "Green Revolution" in recent decades, technological innovation in agricultural production has had a significant contribution to improving agricultural production efficiency, and the large-scale promotion of agricultural technology has played an important role in solving the global food security problem [1]. At the same time, poor soil fertility and excessive chemical inputs have also brought about a series of problems such as income imbalance, environmental pollution, and the declining quality of high-yielding crops [2–4]. Green transformation is a realistic demand globally, especially in developing countries. The application of green production technology including scientific fertilization technology, biological control technology, water-saving irrigation technology, and conservation tillage technology provides the possibility to solve the above problems, which can match the carrying capacity of resources and the environment, coordinate resources and ecological life, and take into account the quantity and quality of agricultural products [5]. For example, China has 200 to 300 million smallholders, accounting for 70% of agricultural land, and has been the dominant force in the country's food production. However, smallholders have limitations such as low technology awareness and poor-risk resistance [6]. Additionally, considering the limitations of the technology itself (e.g., high complexity and slow short-term results), these multiple factors have hindered the smallholders' adoption of green production technology, which has become a barrier to agricultural transformation [7]. Therefore, this has become a priority for the green transformation of agriculture to study smallholders, identify their technological demands and barrier factors, and improve their technology adoption rate.

Multiple forms of technology promotion have been explored to facilitate the rapid application of green production technologies in agriculture. On one hand, there are agricultural technology extension centers, enterprise agricultural technicians, and other organizations in the form of field schools, training sessions, and other forms of technological innovation, introduction, dissemination, and application [8,9]. On the other hand, through university researchers working with smallholders on localized adaptive technology innovations, the level of technology awareness and adoption among smallholders is increased [10]. For example, changing the smallholders' decisions on food crop density and training smallholders in integrated management techniques can significantly increase the food crop yields, reduce fertilizer use, improve fertilizer use efficiency, and reduce environmental emissions [11,12]. In China, a "top-down" technological innovation led by the government or universities has increased the national grain yield (wheat and maize) by 33 million tons (about 10.8% to 11.5%) and saved 12,000 tons of nitrogen fertilizer, ensuring not only food security but also environmental protection goals [13].

As the main body of agricultural production, the green production technology demands of smallholders are influenced by many factors. For example, family characteristics such as age and education level, human capital characteristics such as personal values and social trust, land characteristics such as planting area and land quality, and external environmental characteristics such as technology supply, technology training, and government policies [8,9,14]. In recent years, with the improvement in comprehensive human capital quality, research on the influence of the technology awareness of smallholders on their willingness to adopt green production technologies has received extensive attention from scholars [15]. Studies have shown that technology awareness and the increased technological benefits expected are the main means of promoting the adoption of green production technologies. For example, economic benefits drive the active adoption of organic fertilizer application technologies by smallholders of cash crops [6]. Therefore, meeting the demands and willingness of smallholders to shift from passive to active learning and improve their knowledge of green production technology can make achieving green transformation in agriculture in an easy manner [16].

The existing research was conducted to lay a fruitful theoretical foundation for research related to the adoption of green production technologies by smallholders based on the theory of the green innovation adoption model, institutional theory, and stakeholder theory [17–19]. However, there are still deficiencies in the following two aspects. On one hand, most studies have only focused on the magnitude of the coefficients of the influencing factors that affect the smallholders' adoption of green production technologies, ignoring the relationship and hierarchy between different factors [20]. For example, in the research on organic fertilizer technology adoption, differences in the factors affecting the adoption of organic fertilizer technology among the grain, vegetable, and fruit tree growers were found [6], but why this difference exists, and what the reasons are for the differences between the different factors remain unclear. On the other hand, most of those studies have measured only a single technology (e.g., soil testing and fertilization technology) as representative of green production technologies, while in fact, green production technology includes not only soil testing and fertilizer application technology, but also land, water, pest and disease control, and other multifaceted technologies, which bias the results due to the existence of technology differences [21]. Although it is easier to develop research on a single technology, the analysis of the factors influencing the adoption of green production technologies by smallholders, especially the understanding of the correlations between different factors, has not been fully understood.

Thus, this study aimed to (i) investigate the willingness and intensity of smallholders of food crops to adopt different types of green production technologies; (ii) assess the direct and root factors influencing the adoption of green production technologies by smallholders; (iii) clarify the hierarchical linkage between the factors influencing the adoption of different green production technologies; and (iv) assess the commonalities and differences between the factors affecting different green production technologies to address the issue of key factors affecting the adoption of green production technologies by smallholders and the hierarchical linkages between different factors affecting the adoption of green production technologies by smallholders. These results provide an empirical reference for improving the green production technology adoption rate in place and the transformation of agricultural green development.

2. Materials and Methods

2.1. Data Source and Variable Selection

2.1.1. Data Source

The data for this study were obtained from a survey of the smallholders' green production technology needs conducted from July to September 2020 around 16 provinces (cities and autonomous regions) in China including Beijing, Hebei, Shanxi, Inner Mongolia, Jilin, Heilongjiang, Shanghai, Anhui, Jiangxi, Shandong, Henan, Guangxi, Chongqing, Sichuan, Yunnan, and Shaanxi, covering key regions of grain production (Table S1). The regions of our study covered the main grain crop production areas such as North China, Northeast China, Northwest China, and the Yangtze River Basin region to ensure the representativeness of the survey sample. Survey areas of wheat, maize, and rice cultivation in the study area accounted for 75.7%, 83.6%, and 60.7% of the national area, respectively [22]. The research sample was selected mainly based on the differences in food crop types and regional resource endowments, based on a multi-stage stratified and random sampling method, with two counties in each province, two townships in each county, two villages in each township, and 10–20 smallholders randomly selected from each village for the research. Based on the actual planting situation of smallholders, we investigated their willingness to adopt green production technology, technology perception, family characteristics, land characteristics, planting characteristics, and other production and management characteristics in several dimensions.

In designing the questionnaire, we first clarified the research topic and the research target of the questionnaire. Second, we determined the research content and specific research questions of the research questionnaire. To ensure the validity of the questionnaire, our researchers were recruited from graduate students of key agricultural colleges in Beijing, China, and were systematically trained on the questionnaire, research requirements, and techniques before the formal research. During training, we explained the notes of the research questionnaire and discussed each question of the questionnaire. The investigators fully understood each question of the questionnaire to ensure the credibility of the results. After eliminating invalid samples, we finally obtained 709 valid samples, which laid a better data foundation for reflecting the overall situation of smallholders nationwide.

2.1.2. Variable Selection and Statistics

Variable Selection

(1) The selection of green production technology. In this research, the willingness to adopt green production technologies and the intensity of the adoption of green production technologies were selected as the explanatory variables. Green production technology includes many kinds of technologies, according to existing studies [23,24]; this research classified green production technology into four categories: scientific fertilization technologies (soil testing and formulated fertilization technology, nitrogen fertilizer backward technology, chemical fertilizer identification technology, micro-fertilizer application technology, stepwise fertilization technology); water-saving irrigation technologies (frozen water irrigation technology, irrigation technique); biological control technologies (one spray three prevention technology, spring grass and autumn treatment, pesticide identification technology, chemical control technology, control technology of caterpillar fungus disease); and conservation tillage technologies (deep tilling and deep loosening technology, straw returning technology, timely land preparation technology), and each category of green production technologies contained some differences in wheat, maize, and rice, which can be found in Table S2 of the Supplementary Materials. First, we stipulated whether a smallholder had the willingness to adopt one or more of the technologies in a category of green production technologies. Then, we considered whether smallholders were willing to adopt that type of green production technology. If the smallholder was willing to adopt this type of green production technology, a value of "1" is assigned, and if not, a value of "0" is assigned. The intensity of willingness to adopt green production technologies is expressed in terms of the number of green production technologies that smallholders are willing to adopt (e.g., if smallholders have the willingness to adopt both scientific fertilization technologies and water-saving irrigation technologies, the intensity of the smallholders' willingness to adopt green production technologies were considered to be "2").

In addition, the following cases require special instructions. First, during the research with smallholders, we will present in detail the green production technology for the whole reproductive period of wheat and maize covered by the questionnaire. Second, we will also present the key issues to be taken into account when applying the technology and the possible costs and benefits of applying the technology. Third, after smallholders were informed about the science and technology of all food crops, then the technology needs of the smallholders were studied. This ensures that smallholder knowledge of each green production technology, the smallholder knowledge of the costs and benefits of each green production technology, and the ability to reflect the smallholder demand for green production technologies. This type of research will allow smallholders to clarify the types and concepts of green production technologies. It also avoids the tendency of smallholders to choose the green production they hear about and makes the research results reliable and meaningful. According to existing studies, in constructing the econometric model, the adoption intention and adoption intensity of green production technologies were selected as explanatory variables. Meanwhile, the adoption intention of four specific categories of green production technologies, namely, scientific fertilization, water-saving irrigation, biological control, and conservation tillage, were used as the explanatory variables in the group regression.

(2) The selection of explanatory variables. The variables needed for this paper were selected based on existing studies including the smallholders' technology awareness, family characteristics, land characteristics, and planting characteristics [6,14,25]. Technology awareness included the smallholders' awareness of production technology and the technological benefits expected. Family characteristics included gender, age, education level, experience of planting, and the number of family members in the household. Land characteristics included the geomorphic type, soil stickiness, and degree of land fragmentation of the smallholders' planted land. Planting characteristics included the types of business entities, the proportion of planting income, cultivated area, planting-breeding type, and crop varieties (Table 1 and Table S3).

Table 1. Variable definition and descriptive statistics.

Variable Category	Variable Name	Description	Mean Value	Standard Deviation
Willingness and intensity of green production technology adoption	Willingness to adopt green production technology	1 = Yes; 0 = No	0.635	0.018
	Intensity of willingness to adopt green production technology		0.990	0.039
	Willingness to adopt scientific fertilization technology		0.425	0.019
	Willingness to adopt water-saving irrigation technology		0.320	0.018
	Willingness to adopt biological control technology awareness		0.109	0.012
	Willingness to adopt conservation tillage technology		0.131	0.013
Technology awareness	Awareness of production technology	1 = Very not understand; 2 = Not understand; 3 = Neutral; 4 = Understand; 5 = Very well understanding	3.353	0.027
	Scientific fertilization technology awareness	1 = Very not understand; 2 = Not understand; 3 = Neutral; 4 = Understand; 5 = Very well understanding	2.724	0.042
	Water-saving irrigation technology awareness		0.740	0.016
	Biological control technology awareness		0.134	0.013
	Conservation tillage technology awareness		3.516	0.040
	Technology benefits expected		3.343	0.050
	Scientific fertilization technology	Will it improve crop yield, quality, and resource utilization? 1 = Yes; 0 = No	0.814	0.015
	Water-saving irrigation technology		0.891	0.012
	Biological control technology		0.023	0.006
	Conservation tillage technology		0.571	0.019
Family characteristics	Gender	1 = Male, 0 = Female	0.701	0.017
	Age	Year	54.444	0.437
	Education level	1 = Elementary school and below; 2 = Junior high school or vocational school; 3 = Senior high; 4 = College for professional training; 5 = Bachelor's degree or above	1.817	0.033
	Experience of planting	Year	30.375	0.533
	Number of family members	Population	4.147	0.064

Table 1. *Cont.*

Variable Category	Variable Name		Description	Mean Value	Standard Deviation
Land characteristics	Geomorphic type		1 = Flatland; 0 = Mountainous, sloping, or depressed areas	0.866	0.013
	Soil stickiness		Whether clayey soil: 1 = Yes; 0 = No	0.051	0.008
	Land fragmentation degree		Number of land parcels	5.726	0.260
Planting characteristics	Types of business entities		Whether it is a cooperative, family farm, large planter: 1 = Yes; 0 = No	0.097	0.011
	Proportion of planting income		Income from farming/total household income. Unit: %	0.566	0.014
	Cultivated area		Hectares	1.705	0.180
	Planting-breeding type		Whether to combine farming and breeding: 1 = Yes; 0 = No	0.131	0.013
	Crop varieties	Are wheat growers	1 = Yes; 0 = No	0.578	0.019
		Are maize growers	1 = Yes; 0 = No	0.798	0.015
		Are rice growers	1 = Yes; 0 = No	0.178	0.014

Variable Statistics

From the statistical results in Table 1, in terms of family characteristics, our research sample was dominated by older men with low education levels. Since the heads of Chinese rural households are basically male, the research subjects were predominantly male. The data showed that the average age of smallholders was 54.4 years old, the average number of family members was 4.1 persons, and the average education level was 1.8; most of them were below junior high school or vocational school level. In addition, smallholders have rich experience in planting, with an average of 30.4 years of farming. In terms of the land characteristics, most of the samples were in plain areas with neutral soils, and the average household owned 5.7 plots of land, which had the problem of land fragmentation. In terms of the planting characteristics, most of the researched smallholders did not join cooperatives, family farms, or large planters. The average cultivated area of households was 1.7 ha, and fewer of the smallholders were combined farming and breeding.

The statistical results of the willingness and intensity of green production technology adoption and technology awareness showed that the technology adoption intention of smallholders was relatively high, but there were large differences in the awareness of the production technology and technological benefits expected, which are consistent with the reality of traditional Chinese rural areas, indicating that the results of this research have reliability and credibility.

2.2. Logit Model

In this study, to clarify the factors affecting the adoption of green production technologies by smallholders, the logit model was selected for analysis as follows:

$$P = F(y = 1|X_i) = \frac{1}{1 + e^{-y}} \tag{1}$$

where y is the willingness of smallholders to adopt green production techniques, y = 1 is willing, y = 0 is unwilling; P is the probability of the smallholders' willingness to adopt green production technologies, $P/(1-P)$ is the ratio of the probability that smallholders are willing to adopt green production technologies to the probability that they are unwilling to adopt green production technologies; X_i is the various factors of the smallholders' willingness to adopt green production technologies, i = 1,2, . . . ,n.

In addition, where y is a linear combination of variables x_i (i = 1,2, . . . ,n).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n \tag{2}$$

where β_i (i = 1,2, . . . ,n) is the regression coefficient of the explanatory variable.

Combining Equations (1) and (2), the logit model in the form of the occurrence ratio is obtained.

$$Ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon \tag{3}$$

Significant factors affecting the smallholders' willingness to adopt green production technologies were obtained using stepwise regression.

2.3. Interpretative Structural Modeling (ISM)

The ISM method is a modern analytical approach to systems engineering, which is typically used for exploring the system structure and hierarchy, identifying the key factors of the system, and studying the hierarchy among the factors [26]. Therefore, this method was selected for further hierarchical analysis of the factors influencing the smallholders' adoption of green production technologies. This was based on the basic process of the ISM method and those of the logit model to form a multilevel, ladder-like influence structure, thus affecting the smallholders' green production technologies [20].

Based on the aforementioned logit model results, logical relationships among the factors influencing the willingness of smallholders to adopt green production technologies were identified. Here, S_i (i = 1,2, . . . ,k) is the multiple factors influencing the willingness of smallholders to adopt green production technologies and defines the elements r_{ij} in the adjacency matrix $\boldsymbol{B}$ according to Equation (4).

$$r_{ij} = \begin{cases} 1, & S_i \text{ is related to } S_i \\ 0, & S_i \text{ is not related to } S_i \end{cases} \tag{4}$$

where i = 0,1,2, . . . ,k; j = 0,1,2, . . . ,k. Determine the reachability matrix $\boldsymbol{M}$ according to the following equation:

$$\boldsymbol{M} = (\boldsymbol{B}+\boldsymbol{I})^{n+1} = (\boldsymbol{B}+\boldsymbol{I})^n \neq \cdots \neq (\boldsymbol{B}+\boldsymbol{I})^n \neq (\boldsymbol{B}+\boldsymbol{I}) \tag{5}$$

where $\boldsymbol{I}$ is the unit matrix; n is the power and $2 \leq n \leq k$, and the adjacency matrix $\boldsymbol{B}$ is calculated using Boolean operations to obtain the reachability matrix $\boldsymbol{M}$ for each influence factor.

The structure of each hierarchy was determined. The full set of elements of the highest-level $\boldsymbol{L_i}$ according to Equation (6) is

$$\boldsymbol{L_1} = \{\boldsymbol{S_i} | \boldsymbol{P}(\boldsymbol{S_i}) \cap \boldsymbol{Q}(\boldsymbol{S_i}) = \boldsymbol{P}(\boldsymbol{S_i})\} \tag{6}$$

where $\boldsymbol{i}$ = 0,1,2, . . . ,k; $\boldsymbol{P}(\boldsymbol{S_i})$ is the reachable set, which contains the set of all factors that can be reached by the reachable matrix beginning from $\boldsymbol{S_i}$. $\boldsymbol{Q}(\boldsymbol{S_i})$ is the prior set, which contains the set of all factors that can reach $\boldsymbol{S_i}$ in between. The specific expressions for $\boldsymbol{P}(\boldsymbol{S_i})$ and $\boldsymbol{Q}(\boldsymbol{S_i})$ are as follows:

$$\boldsymbol{P}(\boldsymbol{S_i}) = \{\boldsymbol{S_i} | m_{ij} = 1\},\ \boldsymbol{Q}(\boldsymbol{S_i}) = \{\boldsymbol{S_i} | n_{ij} = 1\} \tag{7}$$

Here, m_{ij}, n_{ij} are the factors that can reach the matrix $\boldsymbol{M}$.

The remaining layers were obtained mainly through the following steps. First, according to the original reachability matrix $\boldsymbol{M}$, the rows and columns corresponding to the factors in $\boldsymbol{L_1}$ were deleted to calculate the new $\boldsymbol{M'}$. Second, for $\boldsymbol{M'}$, the set $\boldsymbol{L_2}$ of the second layer of factors was obtained using Equations (6) and (7), and so on. Factors located in all layers of the hierarchy were obtained. Finally, the hierarchy of the factors affecting the adoption of green production technologies by smallholders was obtained.

3. Results

3.1. Current Status of Smallholders' Green Production Technology Demand

The results from the surveys showed that smallholders had obvious differences in the demand for different green production technologies for food crops. Smallholders had a strong willingness to use scientific fertilization technology (42.4%) and biological control technology (32.0%). Conversely, water-saving irrigation technology (10.9%) and conservation tillage technology (13.1%) had a weak willingness (Figure 1).

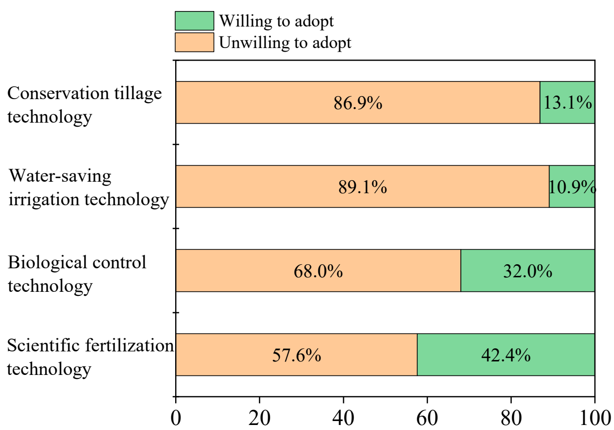

Figure 1. The demand for different green production technologies in food crops.

3.2. Differences in Smallholders' Demands for Green Production Technology

Figure 2 presents the results for the smallholders' green production technology demand. The smallholders' green production technology demands for different food crops varied significantly. The smallholders' technical requirements for green production technology were dominated by both biological control and scientific fertilization technologies. Conversely, the demand for water-saving irrigation technology and conservation tillage technology was relatively low. For wheat and maize, smallholders had similar demands for green production technologies, mainly focusing on biological control (38.8%, 43.2%) and scientific fertilization technologies (29.3%, 39.4%). For rice, smallholders had some demand for all four technologies, with 82.5%, 66.7%, 47.6%, and 36.5% for scientific fertilization technology, biological control technology, water-saving irrigation technology, and conservation tillage technology, respectively.

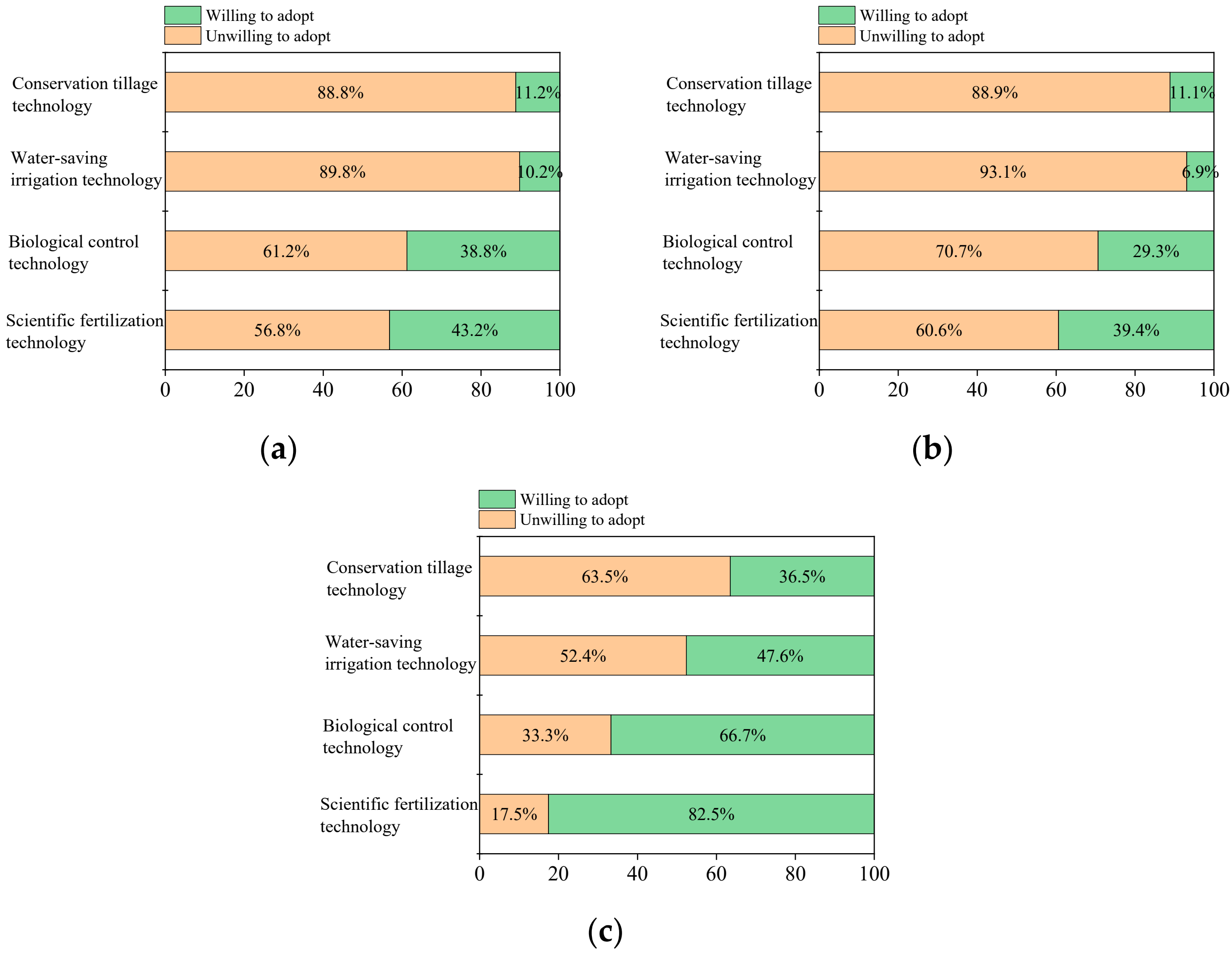

Figure 2. The smallholders' demand for different green production technologies in wheat, maize, and rice. (**a**) wheat (n = 410), (**b**) maize (n = 566), (**c**) rice (n = 126).

3.3. Logit Model Analysis on Adoption Willingness and Intensity of Green Production Technology

The smallholders' willingness to adopt green production technologies and the intensity of their willingness to adopt was influenced by technology awareness, family characteristics, land characteristics, and plant characteristics (Table 2, Figure S1). The results in Table 2 show that the factors influencing the willingness to adopt green production technologies and the intensity of willingness to adopt green production technologies maintained a high degree of consistency. To simplify the presentation, we focused on the factors influencing the willingness to adopt green production technologies in the following analysis.

Table 2. The results of the model fitting of factors influencing the willingness to adopt green production technologies.

Variable Type		Willingness to Adopt Green Production Technology		Intensity of Willingness to Adopt Green Production Technology	
		Coefficient	**Odds Ratio**	**Coefficient**	**Odds Ratio**
Technology awareness	Awareness of production technology	0.271 (0.156) *	1.311 (0.205) *	0.305 (0.113) ***	1.357 (0.153) ***
	Technological benefits expected	0.143 (0.075) *	1.154 (0.087) *	0.148 (0.061) **	1.160 (0.071) **
Family characteristics	Gender	−0.227 (0.214)	0.797 (0.170)	−0.164 (0.170)	0.849 (0.144)
	Age	−0.025 (0.012) **	0.975 (0.012) **	−0.014 (0.010)	0.986 (0.010)
	Education level	−0.350 (0.129) ***	0.705 (0.091) ***	−0.275 (0.101) ***	0.76 (0.077) ***
	Experience of planting	0.018 (0.010) *	1.018 (0.010) *	0.013 (0.008)	1.013 (0.008)
	Number of family members	−0.062 (0.057)	0.940 (0.054)	−0.080 (0.047) *	0.923 (0.043) *
Land characteristics	Geomorphic type	0.659 (0.286) **	1.934 (0.552) **	0.576 (0.243) **	1.778 (0.432) **
	Soil stickiness	1.569 (0.533) ***	4.804 (2.560) ***	1.012 (0.345) ***	2.752 (0.950) ***
	Land fragmentation degree	−0.037 (0.016) **	0.963 (0.016) **	−0.055 (0.014) ***	0.946 (0.013) ***
Planting characteristics	Types of business entities	0.475 (0.340)	1.608 (0.547)	0.049 (0.264)	1.050 (0.278)
	Proportion of planting income	1.160 (0.281) ***	3.191 (0.898) ***	0.721 (0.229) ***	2.056 (0.471) ***
	Ln(cultivated area)	−0.342 (0.231)	0.711 (0.164)	0.324 (0.169) *	1.382 (0.234) *
	Planting-breeding type	0.508 (0.292) *	1.662 (0.486) *	0.196 (0.229)	1.216 (0.279)
	Crop varieties	Controlled	Controlled	Controlled	Controlled
	Constant term	−2.889 (1.012) ***	0.056 (0.056) ***	-	-
	LR chi2(17)	224.150	224.150	391.270	391.270
	Prob > chi2	0.000	0.000	0.000	0.000
	Log likelihood	−353.371	−353.371	−710.143	−710.143
	Pseudo R^2	0.241	0.241	0.216	0.216
	Sample size	709			

* Indicates the significance of the coefficients at $p < 10\%$, ** Indicates significance at $p < 5\%$, *** Indicates significance at $p < 1\%$, and the robust standard errors are in parentheses.

In the technology awareness, the awareness of production technology and the technology benefits expected were significant at the significance level of 10%. It shows that the higher the technological awareness of smallholders, the more likely they are to adopt green production technologies.

In the family characteristics, age was significantly negatively related to the smallholders' willingness to adopt technology at the 5% level, and the regression coefficient of education level was −0.350 and exp(b) was 0.705. As the smallholders' age and education level increased, their demand for green production technology gradually decreased. The experience of planting showed a positive relationship with the smallholders' willingness to adopt green production technology at the 10% level (i.e., a rich experience of planting increased the smallholders' willingness to adopt green production technologies).

In the land characteristics, the geomorphic type and soil stickiness showed positive correlations with the smallholders' willingness to adopt green production technologies at the 5% and 1% levels, respectively (i.e., as land leveling increases and soil quality improves, it will help smallholders to choose green production technologies). The land fragmentation degree showed a significant negative correlation at the 5% level (i.e., an increase in the land fragmentation degree would inhibit the adoption of green production technologies).

In the planting characteristics, the regression coefficient for the proportion of planting income was 1.160 and exp(b) was 3.191, indicating that as the proportion of planting income increases, the more likely smallholders are willing to adopt green production technologies. In addition, we also controlled for crop type, etc., and the results are shown in Table 2.

3.4. Smallholders' Preferences toward Green Production Technology

Further group regressions on scientific fertilization, water-saving irrigation, biological control, and conservation tillage technologies showed that the factors influencing the smallholders' willingness to adopt different types of green production technologies had significant differences (Figure 3, Table S4). Regarding the smallholders' awareness, the willingness to adopt scientific fertilization technology mainly depends on the smallholders' technology awareness; willingness to adopt conservation tillage technology mainly depends on the technological benefit expectations; and willingness to adopt water-saving irrigation technology and biological control technology are both influenced by technology awareness and technological benefit expectations. Regarding family characteristics, willingness to adopt scientific fertilization technologies and water-saving irrigation technologies was mainly limited by education level and the number of family members. Conversely, the willingness to adopt biological control technologies and conservation tillage technologies was mainly influenced by the experience of planting and the number of family members. Regarding the land characteristics, the willingness to adopt water-saving irrigation technologies is mainly influenced by soil stickiness. In contrast, the use of biological control technology was influenced by the education level and experience of planting, while the conservation tillage technology was influenced by the number of family members. Regarding the planting characteristics, the proportion of planting income significantly influenced the willingness to adopt green production technologies. The adoption intentions of biological control and conservation tillage technologies were also influenced by the cultivated area of smallholders. Technology awareness, land characteristics, and planting characteristics are key factors that affect the adoption of green production technologies by smallholders and limit the green transformation of China's agriculture.

	Scientific fertilization technology	Water-saving irrigation technology	Biological control technology	Conservation tillage technology
Awareness of production technology	0.180**	4.114***	0.898**	0
Technology benefits expected	0.089	2.643***	0.970*	1.474***
Gender	−0.260	0.258	0.037	0.029
Age	−0.014	−0.002	−0.014	−0.001
Education level	−0.338***	0.425*	−0.316**	0.056
Experience of planting	0.004	−0.010	0.020**	0.007
Number of family members	−0.157***	−0.213*	−0.081	0.248***
Geomorphic type	0.435	0.489	0.132	0.165
Soil stickiness	0.578	1.209*	0.422	0.589
Land fragmentation degree	−0.015	−0.010	−0.068***	−0.087***
Types of business entities	0.168	−0.667	−0.400	0.352
Proportion of planting income	0.789*	0.761***	0.032***	0.175***
Ln（cultivated area）	−0.196	0.259	0.655***	0.710***
Planting-breeding type	0.226	−0.311	−0.021	0.414

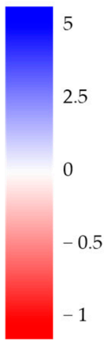

Figure 3. A summary of the regression results between the different green production techniques. Red, white, and blue represent the negative, zero, and positive coefficients, respectively. The darker the color, the greater the absolute value of the coefficient. *, **, *** indicate the statistical significance at the 10%, 5%, and 1% levels, respectively.

3.5. Analysis of Hierarchical Structure Based on ISM

Logit model analysis can only analyze the influencing factors of different green production technologies and cannot analyze the correlation between the influencing factors. Therefore, the analysis using the ISM found that the paths of influencing factors for different green production technology adoption intentions differed significantly (Figure 4).

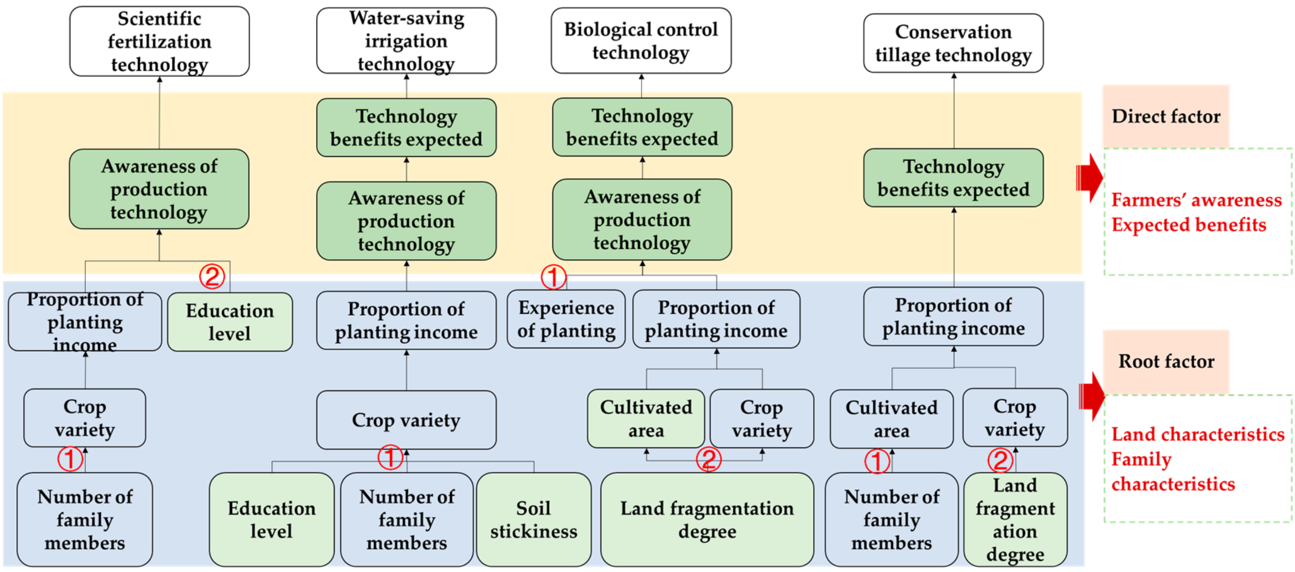

Figure 4. The response paths for green production technologies. The blue underline represents the root factor. The yellow underline represents the direct factors and is indicated by the green box. In the root factors, the light green color represents the highly consistent part of the factors affecting the willingness to adopt different green production technologies. The ① and ② represent the different influence paths.

(1) Two paths can be found for the effect of willingness to adopt scientific fertilization technology. Path one: Number of family members → crop variety → proportion of planting income → awareness of production technology → willingness to adopt scientific fertilization technology. Path two: Education level → awareness of production technology → willingness to adopt scientific fertilization technology.
(2) There is one pathway for the influence of willingness to adopt water-saving irrigation technology. Education level, number of family members, soil stickiness → crop variety → proportion of planting income → awareness of production technology → technology benefits expected → willingness to adopt water-saving irrigation technology.
(3) There are two paths for the influence of willingness to adopt biological control technology. Path one: Experience of planting → awareness of production technology → technology benefits expected → willingness to adopt biological control technology. Path two: Degree of land fragmentation → cultivated area and crop variety → proportion of planting income → awareness of production technology → technology benefits expected → willingness to adopt biological control technology.
(4) There are two paths for conservation tillage: Path one: Number of family members → cultivated area → proportion of planting income → technology benefits expected → willingness to adopt conservation tillage technology. Path two: Degree of land fragmentation → crop varieties → proportion of planting income → technology benefits expected → willingness to adopt conservation tillage technology.

Although there is considerable variation in the factors influencing the adoption of different types of green production technologies by smallholders and the correlations between them, however, the consistency in the root factors and direct factors was strong. Overall, the paths were divided into two dimensions. The farmers' awareness and technological benefits expected were direct factors. The land and family characteristics were the root factors that constrained the smallholders' decision-making behavior in choosing agricultural production technologies.

4. Discussion

4.1. Smallholders Are Generally Willing to Adopt Scientific Fertilization Techniques and Biological Control Technologies

Technology innovation and the precise application of agricultural technologies play an important role in increasing the food production of smallholders [27]. The results of this article show that while smallholders were generally willing to adopt scientific fertilization techniques and biological control technologies (Figure 1), they were also concerned about the benefits they could obtain from growing food crops. The demand for scientific fertilization technology and biological control technology was significantly higher among the rice smallholders than among the wheat and maize smallholders (Figure 2). Other studies also found the same technology demands, with smallholders showing a high willingness to demand the pest control technologies and soil testing and fertilization technologies [16,28,29].

This phenomenon depends not only on the attributes of the smallholders themselves, but also on the characteristics of the attributes of agricultural production technologies. On one hand, the overall quality of smallholders was low and they were more concerned about which agricultural green production technology could better meet the temporary agricultural production needs. In addition, smallholders were concerned about obtaining higher returns in the short-term. Based on this, it can lead to bias in the smallholders' perceptions and needs for agricultural green production technologies [30,31]. On the other hand, there are explicit and implicit effects of agricultural green production technology. For example, the application of scientific fertilization technology and biological control technology can directly affect the growth of crops and increase the profitability of food crops. In particular, the economic value that can be obtained during the cultivation of rice was higher than that of wheat and maize [32]. Therefore, smallholders prefer to use scientific fertilization technology and biological control technology that are easy to control and have fast results [33].

4.2. Technology Awareness and Technology Benefits Expected Are Direct to Influencing Smallholders' Willingness to Adopt the Green Production Technology

The results of this article show that technology awareness and technological benefits are expected to directly influence the smallholders' willingness to adopt technology (Figure 4). The smallholders' technology awareness and technological benefits expected were positively correlated with their willingness to adopt green production technologies (Figure 3).

First, the technology demand of smallholders originated from the level of the smallholders' awareness of green production technologies [15]. A higher awareness of smallholders about green production technologies increased their trust in the technology, reduced the perceived risk, and thus increased their willingness to adopt the technology [34]. Obviously, the smallholders' willingness to adopt technology that was beneficial to improve the food crop production promoted by farming stations, government propaganda, and agricultural technicians will be high, even if they do not know about the technology. Additionally, for the technology attributes, the difficulty of the technology, whether the technology requires the input of responsive machinery, whether it requires long-term training, and whether it requires economic investment all influence the smallholders' perceptions of green production technologies, and thus, their willingness to adopt green production technologies [35].

Second, influenced by economic factors, the smallholders' willingness to demand technology is driven by their expectations of economic benefits. From the results of the statistical analysis, the average proportion of the smallholders' income from cultivation to total household income was about 56.6%, accounting for more than half of the main source of household income (Table 1). Based on the profit maximization principle, the higher the expected returns of smallholders to green production technology, the more they tended to choose green production technology [36].

4.3. Land Characteristics and Family Characteristics Are the Fundamental Reasons Affecting the Adoption of Green Production Technologies

Extensive research has found that the smallholders' attributes, technology awareness, family characteristics, land characteristics, and planting characteristics all influenced their willingness to adopt green production technologies, however, the factors influencing the root factors of smallholder willingness to adopt production technology were farmer attributes [8,15,37]. This finding was similar to the results of this study that the willingness to demand scientific fertilization, water-saving irrigation, biological control, and conservation tillage technologies was influenced by family characteristics, land characteristics, and planting characteristics, and there were significant differences in the factors affecting the willingness of smallholders to adopt different types of green production technologies (Figure 3, Table S4). Therefore, raising the smallholders' willingness to adopt green production technologies is the key to promoting core technologies and facilitating the green transformation of agriculture. Training enables smallholders to quickly accept key technologies such as late-harvesting technology for maize, straw returning technology, and cultivation technology for wheat to increase the yield of food crops [11,38,39]. However, changing the smallholders' willingness to adopt technology is a long-term process. Therefore, addressing the root factors of smallholders' perceptions of technology and its application can enhance their willingness to adopt green production technologies.

4.4. Suggestions for Promoting Smallholders' Adoption of Green Production Technology

Based on the above findings, we can make the following three policy recommendations. First, increase the promotion of high-value-added agricultural cultivation techniques. Research shows that the direct factor of deviation from their behavior and willingness is the financial factor of smallholders [40]. Therefore, based on ensuring food security, we will promote the cultivation model of high-quality wheat and fresh maize to increase the cultivation income of smallholders and drive their willingness and cost to adopt green production technology with economic benefits. Second, increase the smallholders' out-of-school knowledge education by building a platform for smallholder production exchange and technical training to train high-quality smallholders, achieve the optimization of planting patterns and the efficient allocation of resources, and increase the rate of the green production technologies that are in place. Third, enhance the construction of agricultural production infrastructure. As we can see from the previous article, the land fragmentation degree and soil stickiness are all root factors that affect the adoption of green production technologies by smallholders. Therefore, the construction of agricultural infrastructure should be strengthened to reduce the production costs of smallholders and increase the adoption rate of green production technology.

4.5. Limitation Analysis

We evaluated the smallholders' willingness to demand green production technologies in China using abundant farmer survey data on a national scale. However, the present study still has some limitations. First, we analyzed the willingness of smallholders to demand green production technologies, but we did not consider the green production technologies that are currently applied by smallholders and the gap between the demanded green production technologies and the already applied green production technologies. Second, in analyzing factors affecting the green production technology demand of smallholders, we considered the technology awareness and technological benefits expected of the smallholders. However, we ignored the attributes of the green production technologies themselves. Third, both the research method of this study and the distribution of the research points are reasonable. While the amount of data is sufficient to reflect the overall trend, these do not cover all smallholders. Despite these limitations, our results support these conclusions.

5. Conclusions

The smallholders' willingness to adopt green production technologies varied significantly, with a higher willingness to adopt scientific fertilization and biological control technologies and a lower willingness to adopt water-saving irrigation and conservation tillage technologies. In addition, rice smallholders were more willing to adopt scientific fertilization and biological control technologies. The adoption of green production technologies by smallholders was influenced by the technology awareness, family characteristics, land characteristics, and planting characteristics. The results of the path analysis showed that the farmers' awareness and technological benefits expected were the direct factors influencing the demand for green production technologies for smallholders. The land characteristics and family characteristics were the root factors influencing the demand for green production technologies for smallholders. Therefore, accelerating the promotion of green production technologies through the implementation of policies such as increasing the promotion of high-value-added agricultural products and cultivation techniques, increasing out-of-school knowledge education, and enhancing the construction of agricultural production infrastructure can be a potentially viable way to promote green transformation in agriculture.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture12081275/s1, Table S1: The surveyed provinces and acreage of wheat, maize, and rice [22]; Table S2: The green production technology list; Table S3: The variable name and expected direction; Table S4: The results of the model fitting of factors influencing green production technologies. Figure S1: The summary of the overall regression results.

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