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The Willingness and Technology Preferences of Farmers and Their Influencing Factors for Soil Remediation

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Abstract: Farmers are one of the major uncertainty factors in remediation of contamination farmland. Based on the face-to-face questionnaire survey data of 553 farmers in 4 heavy metal-contaminated agricultural soil remediation projects in China, this study used methods, such as structural equation modeling and random forest to explore farmers' willingness to remediate, technology preference, and their key influencing factors for the first time. The results showed that farmers were willing to remediate contaminated soil and preferred phytoremediation, with 82.8% choosing phytoremediation, 12.5% choosing passivation, and 4.7% believing that the soil did not need to be remediated. In terms of willingness to remediate, the perceived benefits from participation in current remediation projects directly contributed to future willingness, with participation status (total impact coefficient 0.86) and perceived benefits (impact coefficient 0.49) being the main factors positively influencing farmers' willingness. With regard to technology preference, technical characteristics (soil quality, 17.1%; secondary contamination, 16.8%; and remediation period, 11.5%) were the main influencing factors. The sustainability of passivation effect and the possible secondary contamination restrict the promotion of passivation, whereas the cessation of agricultural production during the long remediation period restricts the promotion of phytoremediation. It is recommended to increase farmers' willingness to remediate by improving their perceived benefits and continuously overcoming the technical barriers by: (i) developing efficient and green passivators; and (ii) improving the efficiency of phytoremediation as well as intercropping or rotating cash crops while remediating. The results have important reference value for soil remediation in agricultural countries with small arable land per capita.

Keywords: soil contamination; phytoremediation; passivation; farmer; questionnaire survey

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1. Introduction

Owing to rapid industrialization, urbanization, population growth, and a lack of environmental awareness, environmental degradation and pollution problems have emerged [1,2] among which soil heavy metal pollution has become a global environmental dilemma [3,4]. It has been reported that approximately 20% of soil in the world is contaminated, with over 10 million contaminated sites covering more than 20 million hectares of land, more than 50% of which are contaminated with harmful heavy metals [5]. Approximately 600,000 ha of soil in the United States has been contaminated with heavy metals [4]. Approximately 470,000 ha of agricultural soil in Japan has been contaminated with heavy metals [6]. In China, farmland per capita is less than half of the world average, but the total area of farmland contaminated by heavy metals is nearly 20 Mha, accounting for nearly 19.4% of the total farmland [7].

Soil heavy metal pollution brings food security threats and serious economic losses. The combined impact of heavy metal pollution on the global economy is estimated to exceed $10 billion annually [5,8]. A survey supported by the European Commission estimates that the social loss caused by soil pollution is approximately 17.3 billion euros per year [8]. In

China, nearly 12 million tons of grain are polluted by heavy metals every year [9]. Therefore, actions must be taken to remediate contaminated soil. The second and third Sustainable Development Goals (SDGs) for 2030, adopted by the United Nations General Assembly, also articulate the need to mitigate food threats [10]. China attaches great importance to the environmental quality of its agricultural soils. In May 2016, the Soil Pollution Prevention and Control Action Plan was issued, and 200 pilot demonstrations for contaminated soil were conducted. From 2016 to 2021, approximately 38 billion yuan was invested in the field of soil pollution prevention and control. In 2020, there were 668 ongoing soil remediation projects nationwide of which 42.4% were agricultural soil remediation projects.

For heavy metal-contaminated agricultural soil, the remediation mechanisms are based on two basic principles: one is to reduce the concentration of heavy metals in the soil and completely remove the pollutants and the other is to use engineering technology to transform the pollutants to less harmful forms [11–14]. Phytoextraction (phytoremediation) and passivation are the most widely used representative technologies for engineering applications based on the above two remediation principles. Phytoextraction is one of the most promising phytoremediation technologies, which uses the root system of (hyper)accumulators to uptake contaminants from the soil and transfer them to aboveground biomass for accumulation, achieving complete removal of contaminants through gradual harvesting of the aboveground biomass [11,15]. Passivation remediation, also known as chemical stabilization, is a technology that reduces the toxicity and biological effectiveness of heavy metal contaminants in the soil environment by adding exogenous passivators to contaminated soil and converting heavy metals to non-activated, less toxic forms through surface complexation, chemical precipitation, ion exchange, adsorption, and so on [16,17]. However, the remediation of contaminated farmland involves arable land utilization not only in terms of technology [18,19] but also in terms of the behavior of farmers on micro level.

Although contaminated agricultural soil remediation projects are collective actions led by the government, farmers are the closest stakeholders to farmland contamination and the executors of remediation projects. If farmers perceive the remediation technologies to be detrimental to their interests, this may hinder effective implementation of the project, which will be a major uncertainty factor in solving the hidden dangers of food safety, especially for agricultural countries with small per capita arable land. It turns out that a gap exists between farmers' behaviors and policy expectations [20]. Therefore, it is necessary to study how to encourage farmers to actively participate in soil remediation, and farmers' willingness to participate in remediation and their preference for remediation technologies are important factors that should be considered in the formulation of sustainable soil remediation policies.

The study of issues related to farmland from farmers' behaviors and attitudes has become an important research perspective [21,22]. Research shows that with the application of various technologies, farmers' attitudes are increasingly determining the success of land use policies and that research on farmers' attitudes can contribute to policy innovation and practical guidance on many land use issues [21,23,24]. Various studies have examined farmers' behaviors and attitudes under certain policies and explored the factors that influence farmers' decision-making behaviors [19–21,23,25]. The main factors that may influence farmers' behaviors can be divided in household head characteristics, household production characteristics, and technical characteristics [20,26,27]. On the issue of farmland soil pollution, Zhou et al. [19] studied the spontaneous adaption behaviors of farmers in the mining area, such as abandoning farming and adjusting crops, and their results showed that a low level of adaptation perception for which technology was the most important limiting factor followed by money limited the adaptation behaviors of farmers; Yu et al. [28] investigated farmers' comprehensive assessment of the policy of remediation during fallow, such as planting green manure and biological adsorption, and found that it was positively influenced by the cognition of government implementation, the cognition of policy function and the evaluation of value perception. However, phytoremediation and passivation are the two most commonly used techniques for heavy metal-contaminated farmland. There is still a lack of research on farmers' attitudes towards different soil remediation technologies, the constraints restricting farmers' participation in different technologies remain unclear.

In the above context, with the aim of providing a scientific basis for increasing farmers' willingness to participate in remediation, promoting the implementation of agricultural soil remediation projects, and ensuring food security, our study focuses on answering the following questions: What is the attitude of farmers towards soil remediation and what is their preference for remediation technologies? How can farmers' willingness to participate in soil remediation be increased? How can remediation technologies be further optimized from the perspective of farmers? Therefore, in this study, we conducted face-to-face structured interviews with 553 farmers in 4 contaminated agricultural soil remediation project sites in China to: (i) analyze farmers' willingness to remediate and technical preferences in terms of their individual characteristics, household production characteristics, current status of remediation participation, and technical characteristics; (ii) explore the key factors affecting the popularization and application of soil remediation technologies; and (iii) propose suggestions for optimizing technical parameters for remediation in conjunction with farmers' willingness (Figure 1). It is of great theoretical and practical significance to study in depth farmers' willingness and technical preferences to participate in soil remediation projects and to construct an effective participation mechanism. The results of this study will have important reference significance for the remediation of contaminated soil in agricultural countries with small arable land per capita.

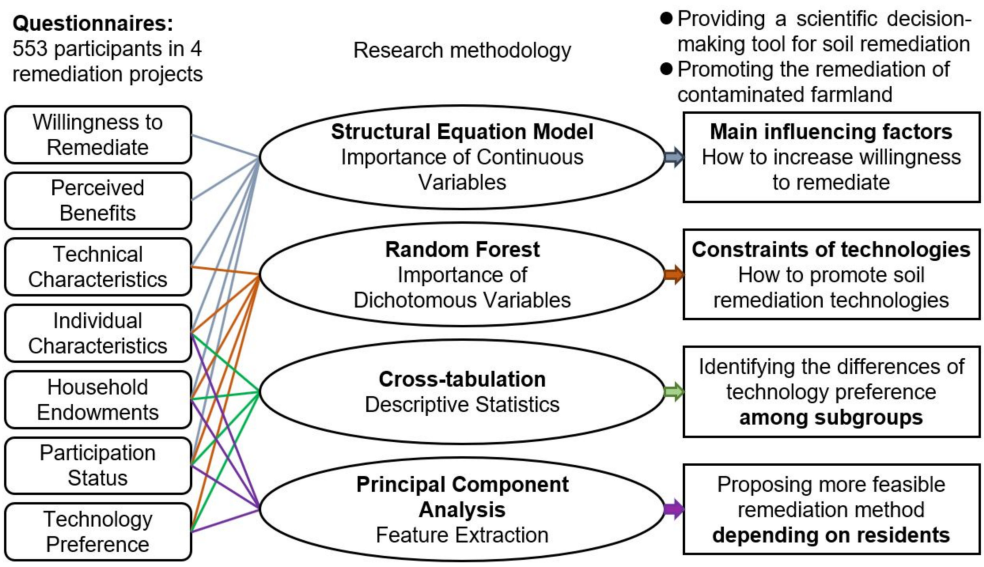

Figure 1. Flow chart of the research.

2. Materials and Methods

2.1. Data Sources

This study surveyed farmers in four soil remediation project areas in China with different levels of soil contamination, where both phytoremediation and passivation remediation were conducted, to ensure that farmers had knowledge of both remediation techniques. Household questionnaire surveys were conducted from January to September 2019 using random sampling and one-to-one structured interview methods. A total of 553 valid questionnaires were obtained from 98 households in Luancheng District, Shijiazhuang City, Hebei Province (A); 147 households in Mianzhu City, Sichuan Province (B); 190 households in Shimen County, Hunan Province (C); and 118 households in Yangshuo County, Guangxi Province (D) (Figure 2). See Supplementary Table S1 for an overview of the study area.

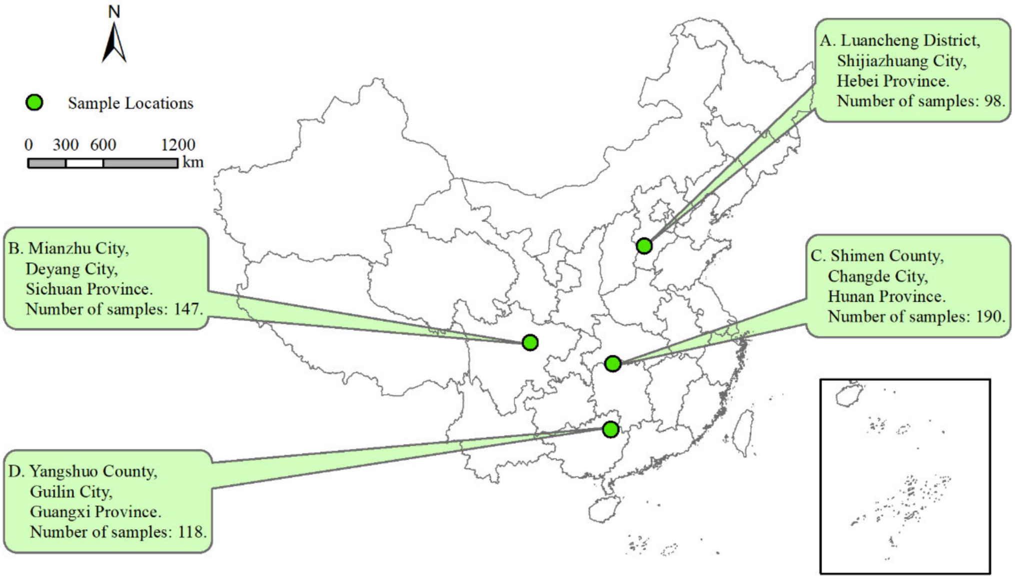

Figure 2. Details of the considered study area.

To ensure the scientific credibility and rationality of the questionnaire, the first draft of the questionnaire was designed through a literature review and expert consultation, which was improved based on the results of a random pre-investigation of 50 farmers in the project area of Shimen County, Hunan Province. The main content of the questionnaire consisted of five parts: basic information about the farmers interviewed (such as gender, age, education), household and production characteristics (including family size, farmland area, income composition), current status of participation in soil remediation (such as farmland area remediated, labor income), satisfaction with current remediation and willingness to remediate in the future, preference for remediation technology, and impact of technical characteristics (see Supplementary Table S2). Among them, farmers' characteristics affect household preferences [29]. Household production characteristics may limit farmers' choices in terms of livelihood strategies, and have received the most attention in recent studies [27,30]. Technology characteristics are farmers' psychological perceptions of different remediation technologies and may influence their rate of adoption of technologies. The participation status is an essential variable and may be an important factor influencing farmers' perceptions of different remediation technologies. To ensure the quality of the survey data, a formal survey was conducted in the form of face-to-face communication between the investigator and respondents, and the investigator filled out the questionnaire.

2.2. Research Methodology

2.2.1. Descriptive Statistics of Farmer Characteristics and Remediation Intentions

To describe the significance of the differences between the backgrounds (individual and household) of the different surveyed populations and the willingness of farmers to participate in future soil remediation and technology selection, a cross-tabulation function in IBM SPSS Statistics software (version 24.0) was used. The remediation and technical intention (non-participation, passivation, phytoremediation) were taken as columns, and the characteristics of farmers were taken as rows to compare the frequency distribution of two independent samples of the rows and columns. Among the characteristics of farmers, continuous variables, such as farmland and income, were defined and transformed into 5-level categorical variables to represent different levels of population. Based on the chi-square test to determine its significance, the original hypothesis of the cross-tabulation was that the two variables of rows and columns were independent of each other. If the chi-square test statistic was less than the critical value of significance level 0.05, the original hypothesis was overturned, indicating that there was a significant difference in remediation technology intention between different row variables (farmers' characteristics). Supplementary Table S2 presents the descriptive statistics of the sample farmers' characteristics.

2.2.2. Structural Equation Model of Farmers' Willingness to Remediate

To study the main factors influencing farmers' willingness to participate in soil remediation, a structural equation model (SEM) was constructed using IBM SPSS Statistics Amos 24.0, which is a widely used method in the study of farmers' behaviors and attitudes, mainly for continuous variables. SEM mainly focuses on modeling the relationships among latent variables, which can effectively solve the problem of farmers' cognition and other problems that are difficult to directly observe, and clearly depicts the behavioral and attitudinal processes of farmers [23,31]. Models using SEM can be divided in two types: measurement and structural models. The measurement model describes how latent variables are measured or conceptualized by corresponding observable variables and is established based on factor analysis, whereas the structural model describes the relationship between different latent variables and is established based on path analysis.

The matrix equations of the measurement model are:

$$X = \Lambda_x \xi + \delta \tag{1}$$

$$Y = \Lambda_y \eta + \varepsilon \tag{2}$$

where ξ and η are exogenous and endogenous latent variables, respectively; X is the exogenous observable variable corresponding to ξ; Y is the endogenous observable variable corresponding to η; Λ_x is the loading matrix of X on ξ; Λ_y is the loading matrix of Y on η; and δ and ε are the measurement errors of X and Y, respectively.

The matrix equation of the structure model is:

$$\eta = \Gamma \xi + \zeta \tag{3}$$

where Γ denotes the effect of ξ on η and ζ is the explanatory error vector that represents the residual term of the structural equation.

In general, farmers' individual characteristics, such as age, gender, and education, household endowments, such as household income and farmland area, and technical characteristics may influence their attitudes toward soil remediation [21,27,32]. Perceived benefits represent the subjective evaluation of soil remediation by farmers. Based on the relevant literature [33,34] combined with the actual situation, we set up questions to evaluate the perceived benefits of farmers, such as whether remediation affects food supply and whether the household income increases. In this study, we surveyed farmers in areas where soil remediation projects have been carried out, whose current participation status in remediation may have been influenced by factors, such as individual characteristics, household endowments, and may have an impact on future intentions. Therefore, we constructed a framework with individual characteristics, household endowments, technical characteristics, participation status, and perceived benefits as exogenous latent variables, and farmers' willingness as endogenous latent variable (Figure 3). The 18 observable variables under the 6 latent variables were all continuous variables and measured uniformly on a 5-level Richter scale. The variable descriptions and statistical values are presented in the Supplementary Table S3.

To examine the evaluation of model, fit indices were used, particularly chi-square, the ratio of chi-square to degrees of freedom (Chi/DF), the goodness of fit index (GFI), adjusted goodness of fit index (AGFI), and root mean squared error of approximation (RMSEA). Both GFI and AGFI estimates ranged from 0 to 1, and if the value was above 0.9, it was acceptable. The acceptable model fit indicated by RMSEA value is 0.08 [35].

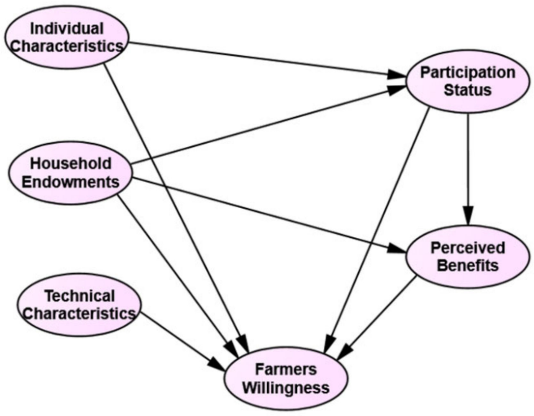

Figure 3. Framework analyzing the factors influencing farmer's willingness to participate in soil remediation.

2.2.3. Random Forest Model of Farmers' Technology Preferences

To explore the main factors influencing farmers' technology preferences for soil remediation, random forest (RF) dichotomy algorithm was used. The RF is a combined classification model based on classification and regression tree (CART), which is a supervised machine learning algorithm that can obtain small errors and high classification accuracy from a limited training set of samples and can be used to evaluate the importance of impact factors [36]. In RF, each node is split using the best value in a randomly selected subset of predictor variables at that node. This counterintuitive strategy performs efficiently compared with many other data mining techniques, including discriminant analysis, support vector machines, and neural networks, and is robust to overfitting [36].

The RF model was constructed using R4.2.1 software with the dichotomous variable of farmers' technology preference to phytoremediation or passivation as dependent variables and farmers' individual characteristics (gender, age, education), household endowment (such as population, farmland, income), participation status, and technological characteristics as independent variables, and finally the Gini index method was applied to evaluate the importance of the variables influencing farmers' technology preference classification. MeanDecreaseGini calculates the impact of each variable on the heterogeneity of the observations at each node of the classification tree using the Gini index, thus comparing the importance of the variables. The larger the value, the greater the importance of the variable. In this study, we normalized all variable importance indices to sum to 100% for presentation [37]. A total of 18 independent variables were used as the original survey data. The variable descriptions and statistical values are presented in the Supplementary Table S7.

2.2.4. Farmer Features Extraction

To further extract the characteristics of farmers who chose each remediation technology, a principal component analysis (PCA) was performed on the data of farmers who chose phytoremediation and passivation separately (IBM SPSS Statistics 24.0). The validity of each variable was determined based on the communality, which indicates how much each variable is expressed by the common factor, and it is generally accepted that variables greater than 0.7 are well expressed by the common factor. Therefore, we used the variables with a communality greater than 0.7 as factors that better summarize the characteristics of the farmers (households) selected for a certain remediation technology. The frequency distribution of these variables was determined to identify the characteristics of farmers who chose this remediation technology.

Data calculations and statistical analyses were performed using Microsoft Excel 2019 and IBM SPSS Statistics 24.0. Figures were drawn using OriginLab Origin 2022.

3. Results and Discussion

3.1. Farmers' Characteristics and Remediation Intention

With the development of existing soil remediation projects and a better understanding of the two remediation technologies, farmers' intentions for soil remediation have changed, and phytoremediation has become a popular remediation mode. Farmers with farmland transferred for soil remediation were defined as those participating in remediation. Among the 553 sample farmers, 22.6% did not participate in remediation, 54.1% participated in phytoremediation, 13.9% participated in passivation, and 9.4% participated in both remediation modes. Regarding future soil remediation intentions, 4.7% of the sample farmers believed that the soil did not need remediation, 82.8% expressed a preference for phytoremediation, and 12.5% preferred passivation (Figure 4a).

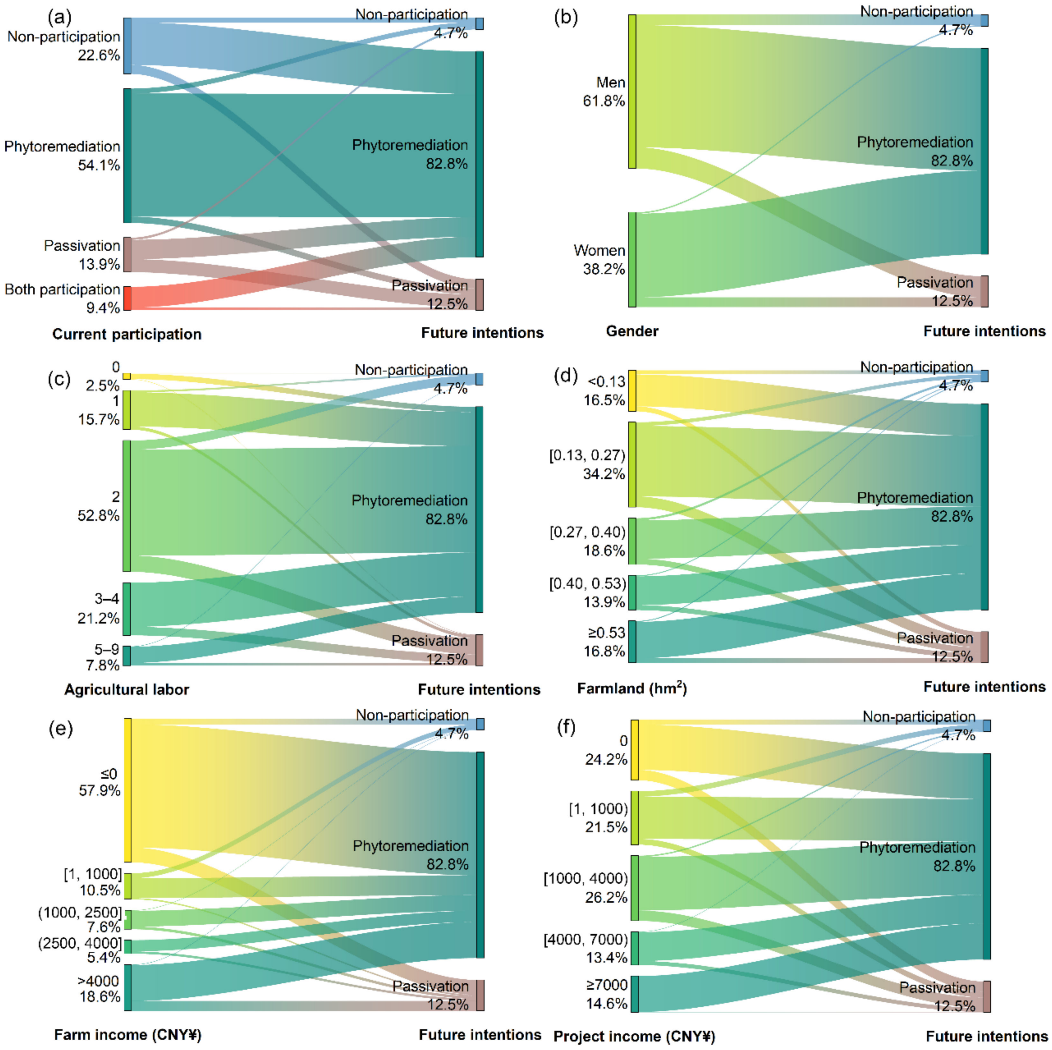

Figure 4. Farmers' characteristics and remediation intention. Future intentions of farmers with different (**a**) current participation, (**b**) gender, (**c**) agricultural labor, (**d**) farmland, (**e**) farm income, (**f**) project income for soil remediation.

Among the objective indicators of the sample farmers' characteristics (Supplementary Table S2), there were significant differences ($p < 0.05$) in soil remediation intentions among different levels of the population in terms of gender, agricultural labor, farmland, farm income, and project income.

- Women had a greater willingness to remediate than men (Figure 4b). Studies often show that women in agriculture are more environmentally conscious than men [38], which may be related to the fact that women are generally more risk-averse than men [25,39,40];

- Farmers with more household agricultural labor had a greater willingness to remediate and an increased propensity to passivation compared with those with less agricultural labor (Figure 4c). Consistent with the findings of Ponce, et al. [41], agricultural labor has a positive impact on households' environmentally friendly behavior. In this study, they preferred passivation in order to ensure "no unemployment";
- Farmers with more farmland were more willing to remediate than those with less farmland (Figure 4d). According to hierarchical theory assumptions, once basic material needs can be met, one can focus on improving quality of life, such as environmental quality [41]. Hence, households with more farmland would be more willing to participate in soil remediation after a portion of their farmland production meets their basic needs;
- Farmers with a high farm income had an increased propensity to passivate relative to those with a lower farm income (Figure 4e). In order to maintain the stability of agricultural production and household economy, households with high income from farmland needed to take adaptation measures [19]. At the same time, they had to maintain the agricultural production function of the soil and thus had an increased propensity for passivation;
- Farmers with high project income had an increased propensity for phytoremediation relative to those with lower project income (Figure 4f). This is attributed to the fact that phytoremediation requires more labor for hyperaccumulator management, with 72.3−100% of the high project income coming from phytoremediation. Economic benefits are generally regarded by scholars as the starting point for farmers' participation in farmland conservation [42]. Economic incentives are often used as a means of increasing farmers' perceptions of adaptation and thus their adaptive behavior [43]. In this respect, phytoremediation has an advantage over passivation.

Agricultural research has observed relationships between farmers' environmental behavior and various demographic characteristics, such as age, education, and gender, which may be associated with decisions to participate in agri-environmental programs [38]. Many studies have shown that farmer's age and education level are key factors influencing their environmental behaviors [27]. Younger farmers are more likely to engage in adaptive production behaviors or environmental improvements than older farmers [27,44], and farmers with higher education levels are more likely to engage in health-related adaptive behaviors [19]. In contrast, farmers' willingness to remediate soil in this study was not significantly related to their age or education level. This may be explained by the high attrition of young labor in our study area (only 3.1% under the age of 40) and the generally low educational attainment of the remaining middle-aged and older labor force (only 8.5% high school and above), a common phenomenon in rural China, resulting in an under-representation of younger and better-educated farmers in the samples.

3.2. Farmers' Willingness to Remediate Soil

The results of the SEM showed that the five exogenous latent variables explained 95% of the variability in farmers' willingness to remediate soil and that participation status and perceived benefits were the main factors influencing the strength of farmers' willingness to participate in soil remediation (Figure 5). The direct path coefficient of participation status on farmers' willingness to remediate was 0.42, and it indirectly affected farmers' willingness by affecting perceived benefits, with a total path coefficient as high as 0.86. There was a significant positive correlation between the two ($p < 0.05$), indicating that the more actively farmers participated in remediation, the stronger their willingness to remediate soil in the future. In terms of each observable variable of participation status, PS1 (farmland area for remediation) had the largest contribution, with a standardized coefficient of 0.98, followed by PS2 (project labor income) with a standardized coefficient of 0.78.

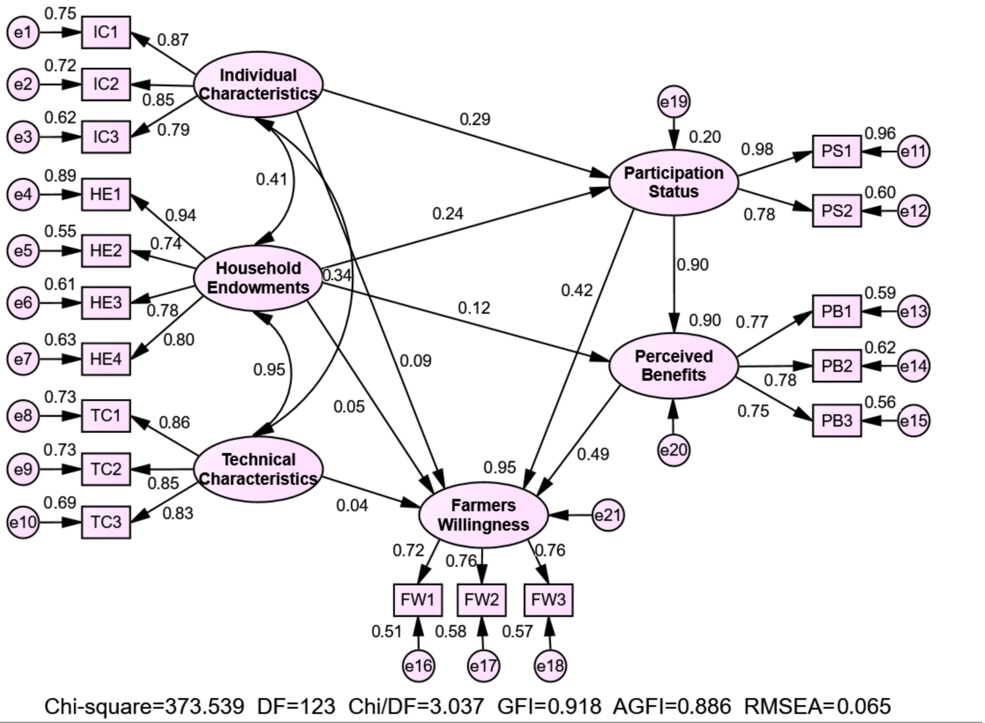

Figure 5. SEM of farmers' willingness to participate in soil remediation. Note: From the unstandardized regression weights, there were only two insignificant paths ($p > 0.05$): household endowments to farmers' willingness and technology characteristics to farmers' willingness. The reliability analysis and validity tests of the model are presented in Supplementary Tables S4–S6.

The path coefficient for the effect of perceived benefits on farmers' willingness to remediate was 0.49, with a significant positive correlation ($p < 0.05$), indicating that the higher the farmers' perceived benefits of participating in remediation, the stronger their willingness to remediate soil in the future. In terms of each observable variable of perceived benefits, the contribution of each observable variable was close, with a PB2 (subsidies for participation in remediation can cover losses) standardized coefficient of 0.78, followed by a PB1 (remediation does not affect food supply) standardized coefficient of 0.77, and a PB3 (participating in remediation can improve income) standardized coefficient of 0.75. This indicated that the farmers' perceived benefits were sourced more from the non-loss of contaminated farmland; that is, it was necessary to ensure that at least the farmland involved in soil remediation had an income comparable to that of farmland with normal production functions.

According to rational behavior theory, perceived value is the comparison between the benefits and risks that farmers experience from their behavior. Individual farmers' behaviors follows the paradigm of "cognitive trade-off–perceived value–willingness to act–behavioral response" in action logic [20,45]. Perceived benefit refers to the result of subjective evaluation made by individuals through product benefits, service quality, emotional satisfaction, and so on [46]. In the study of farmers' economic behavior, perceived benefits are considered an important basis [20]. The higher the level of farmers' perceived benefits, the higher the level of comprehensive assessment. A high level of perceived benefits reflects farmers' positive attitudes towards agricultural policies [23]. Similar results were obtained in this study, where farmers' perceived benefits from participation in current soil remediation projects to obtain land rent and labor income directly contribute to future willingness to remediate. The perceived risks came mainly from the possible risks associated with the technical characteristics of remediation, which were much smaller than the health risks of soil heavy metal stress, and had little impact on farmers' willingness to participate in remediation (path coefficient of 0.04, technical characteristics).

3.3. Farmers' Technology Preference

The RF results showed that technical characteristics were the most important factors in dichotomizing farmers' choice of phytoremediation or passivation; they followed the order: soil quality > secondary contamination > remediation period (Figure 6a). Although farmers' attention to technical characteristics had little effect on their willingness to participate in soil remediation, it directly affected their preference for remediation technologies.

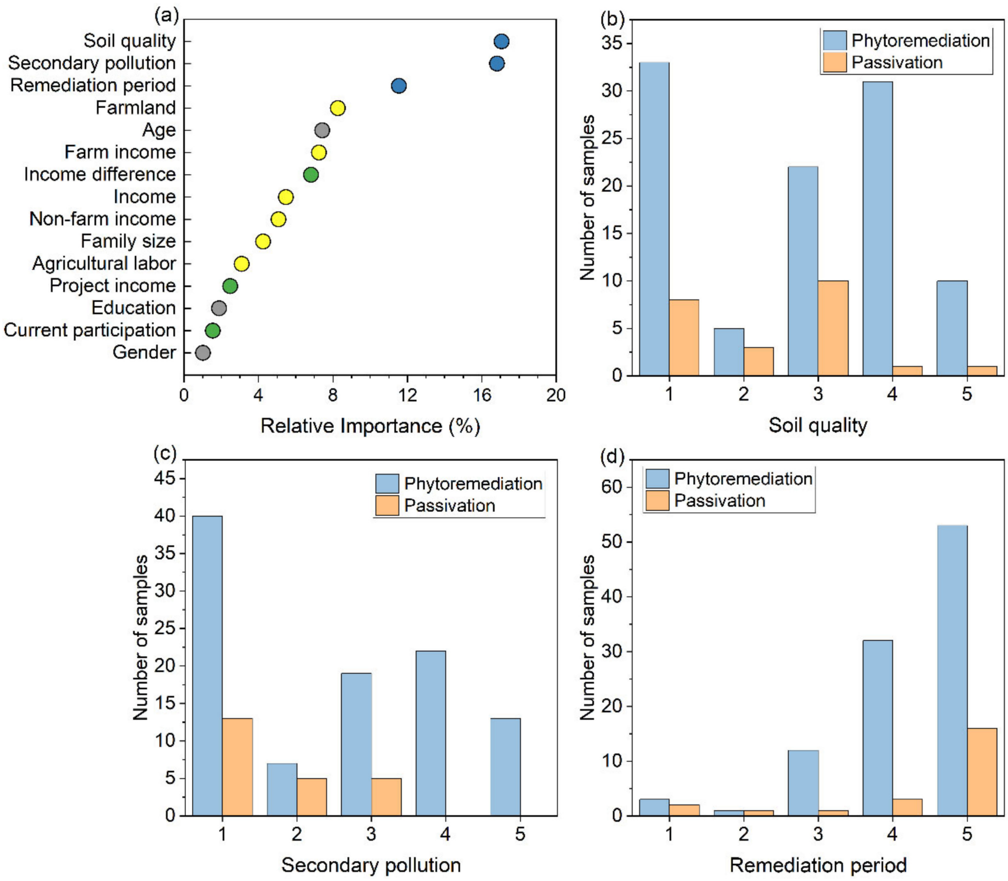

Figure 6. Factors influencing farmers' technology preference. (**a**) The relative importance of the variables of farmers' technology preference. Frequency distribution of respondents' scores on (**b**) soil quality, (**c**) secondary pollution and (**d**) remediation period. Note: (**a**) was based on the results of the MeanDecreaseGini of the RF, and the sum of all factors was normalized to 100%. Then, the importance values of the independent variables were readjusted. The blue, yellow, green, and gray circles are technical characteristic variables, household characteristic variables, current participation variables, and personal characteristic variables, respectively. There were significant differences ($p < 0.05$) in the scores of soil quality, secondary contamination, and remediation period between the sample farmers who chose phytoremediation and passivation after the Mann–Whitney U test (data not normally distributed).

Specifically, the relative importance of soil quality was 17.1%. The scores of farmers who chose phytoremediation and passivation on soil quality were 3.57 ± 1.21 and 2.49 ± 1.04, respectively, indicating that farmers who paid more attention to the possible impact of remediation technology on soil quality were more inclined to choose phytoremediation (Figure 6b). The relative importance of secondary contamination was 16.8%. The scores of farmers who chose phytoremediation and passivation on secondary contamination were 3.57 ± 1.21 and 2.49 ± 1.04, respectively, indicating that farmers who were more concerned about possible secondary contamination from remediation technologies were more inclined to choose phytoremediation (Figure 6c). Passivation remediation has been proven to be an effective, convenient, and low-cost remediation method [16,47], and many passivators have been widely used in remediation practices for metal-contaminated soils [48]. However, the durability of the stabilization effect of passivation under dynamic environmental conditions during long-term remediation and the possible negative effects of passivator application (secondary contamination) remain well-known bottlenecks [16,28,49]. At the same time, these technical barriers to passivation are the main factors limiting its application in agricultural soil remediation.

The relative importance of the remediation period was 11.5%. The scores of farmers who chose phytoremediation and passivation on remediation period were 4.11 ± 0.96 and 4.62 ± 0.97, respectively, suggesting that farmers who placed more value on the remediation period had a higher propensity for passivation (Figure 6d). Phytoremediation is recognized as an eco-friendly, green, and sustainable approach to soil remediation, but it also faces important performance and efficiency issues. For most heavy metals, remediation of contaminated soils by phytoremediation alone spans decades [50,51]. That is, agricultural production needs to be interrupted for a long period, which is also the main factor restricting farmers' choices of phytoremediation. From another perspective, a higher score (full score of 5) indicated that the remediation period was a factor that farmers care about when participating in soil remediation. The desire for healthy soil quality was evident in the fact that some farmers undertake a longer remediation period to bring their farmland back to full health.

3.4. Farmers Feature Extraction

Based on the results of the PCA (Supplementary Tables S8–S11) of the communality, annual income, non-farm income, and education were the factors that best summarized the characteristics of the farmers who selected phytoremediation (Figure 7a). Taking the range of obviously higher frequency distribution of the factors as the characteristics of the main farmers (households) who chose this technology, it can be seen that the main characteristics of farmers who chose phytoremediation were annual household income of 0−16,000 CNY ¥/y (Figure 7b), non-farm income of 0−4000 CNY ¥/y (Figure 7c), and education level of primary school (Figure 7d).

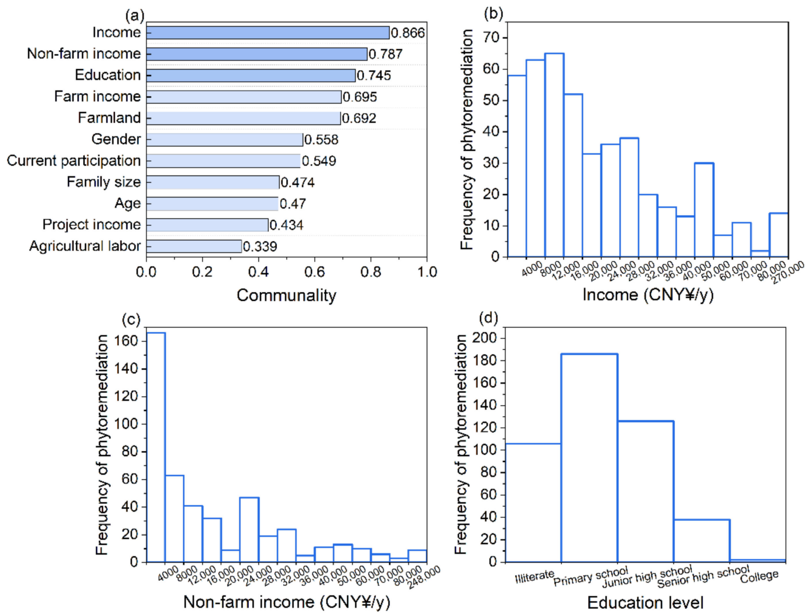

Figure 7. Characteristics of farmers intended for phytoremediation. (**a**) communality of characteristics of farmers intended for phytoremediation extracted by PCA. The dark blue, communality > 0.7. Frequency distribution of (**b**) income, (**c**) non-farm income, and (**d**) education level of farmers who chose phytoremediation.

Farm income, annual income, agricultural labor, and farmland were the factors that best summarized the characteristics of the farmers who chose passivation (Figure 8a). From the frequency distribution plot of each factor, the main farmer (household) characteristics for selecting passivation were farm income ≤ 0 (Figure 8b), annual income of 4000−8000 CNY ¥/y (Figure 8c), agricultural laborers of 3 (Figure 8d), and farmland area of 0.13−0.4 hm^2 (Figure 8e).

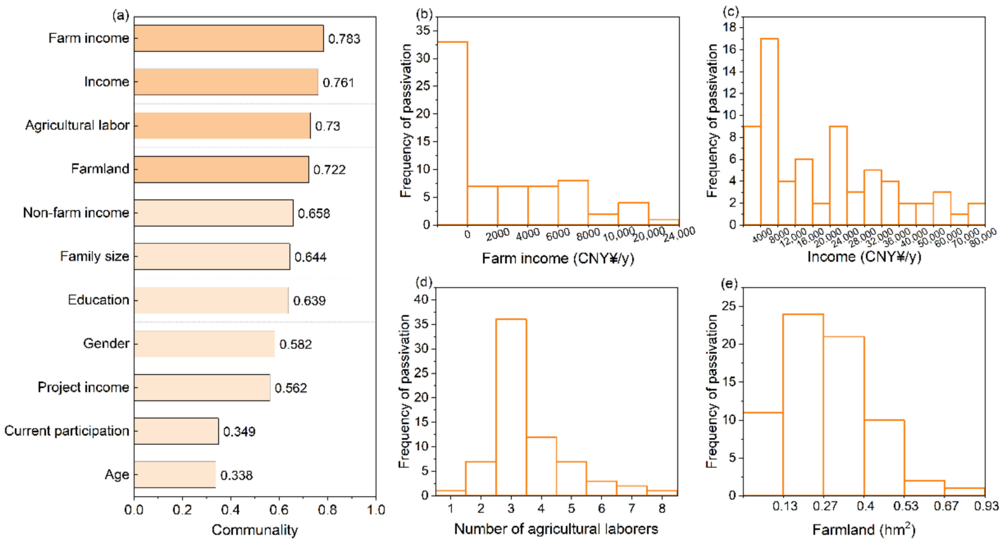

Figure 8. Characteristics of farmers intended for passivation. (**a**) communality of characteristics of farmers intended for passivation extracted by PCA. The dark yellow, communality > 0.7. Frequency distribution of (**b**) farm income, (**c**) income, (**d**) agricultural labor, and (**e**) farmland of farmers who chose passivation.

When formulating soil remediation policies, the farmers' characteristics archived by the local government can be used to preliminarily identify their possible soil remediation technology preference based on the above results, which can be included as one of the important considerations in the comparison of technology options to further ensure the successful implementation of soil remediation projects from the aspect of farmers' willingness to participate.

4. Conclusions

Based on 553 farmers' face-to-face questionnaire data from four heavy metal-contaminated agricultural soil remediation project sites in China, this study explored farmers' willingness and technology preference for agricultural soil remediation and their key influencing factors using SEM, RF, and other methods.

(1) In general, farmers in the survey area were willing to remediate the soil and preferred phytoremediation;

(2) Perceived benefits was the main factors influencing farmers' willingness to participate in soil remediation. The perceived benefits of land rent and labor income received by farmers through their participation in current soil remediation projects directly affected their willingness to remediate in the future;

(3) Technical characteristics (soil quality, secondary contamination, and remediation period) were the most important factors for farmers to choose remediation technologies. The sustainability of soil heavy metal passivation and possible secondary contamination were the main factors limiting farmers' choices of passivation remediation. The long remediation period and cessation of agricultural production were the main factors limiting farmers' choice of phytoremediation.

5. Recommendations and Limitations

The main conclusions of this study have the following implications for the promotion of soil remediation technology and the formulation of policies to improve farmer satisfaction. For scholars: first, further develop efficient and green passivators to overcome the sustainability and possible secondary pollution problems of passivation; second, further develop the corresponding activators with hyperaccumulator applications to improve the efficiency of phytoremediation. For companies: strengthen the long-term supervision after remediation to promote the safe application of passivators. For government: when applying phytoremediation, consider intercropping or crop rotation remediation modes of low-accumulation crops with hyperaccumulators without interrupting production; in areas where farmers' willingness to remediate soil is low, increase their satisfaction and willingness by raising the level of their perceived benefits. These suggestions for government and companies should be carefully considered when carrying out soil remediation to solve food safety problems, especially in agricultural countries with limited per capita arable land.

This study investigates farmers' willingness and technology preference to participate in soil remediation and the important influencing factors to provide a scientific basis to promote the remediation of heavy metal-contaminated farmland from farmers' perspectives. However, there are some limitations in this study. First, we only surveyed 553 farmers in 4 different regions of China, although the study areas have different pollution levels and cropping structures, the limited sample size may bias the results, and the generalizability to other countries and regions needs to be further verified. Second, we only investigated phytoremediation and passivation, the two most commonly used techniques for heavy metal contaminated farmland, without considering other techniques, such as alternative planting and deep plowing, which deserve further study. Third, our questionnaire did not involve subjective indicators, such as government implementation perceptions and subjective norms that may affect farmers' participation behaviors, which should be considered more comprehensively in future studies. Therefore, future study will consider more study areas, more technologies applied in remediation practices of heavy metal contaminated farmland, and it will construct a theoretical framework of farmers' participation behaviors toward different soil remediation technologies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11101821/s1, S1: Table S1 Survey area; S2: Survey questionnaire; S3: Table S2 Descriptive statistics of sample farmers; S4: SEM, Table S3 Variable description and data statistics of the SEM, Table S4 Latent variable reliability test, Table S5 KMO and Bartlett's test, Table S6 Model structure validity (model fitness); S5: Random forest, Table S7 Random forest variable descriptions and data statistics; S6: Principal component analysis, Table S8 KMO and Bartlett's test (phytoremediation), Table S9 Total variance explanation of PCA (phytoremediation), Table S10 KMO and Bartlett's test (passivation), Table S11 Total variance explanation of PCA (passivation).

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