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Factors Affecting Farmers' Environment-Friendly Fertilization Behavior in China: Synthesizing the Evidence Using Meta-Analysis

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Abstract: Excess fertilization is a major cause of agricultural environmental pollution. However, different studies attribute farmers' fertilization behavior to different factors, hindering theoretical and empirical development. Using a meta-analysis of 64 empirical studies on Chinese farmers' fertilization behavior, this study first systematically collects, combines, and analyzes the existing studies to identify the key influencing factors that may affect farmers' environment-friendly fertilization behavior (FEFB) in China. A meta-regression analysis is further applied to explore how the effects of the factors identified have changed over time. The results showed that the key factors include gender, health status, risk attitude, family size, farm size, environmental concern, social norms, cadre status, and policy propaganda. Over time, the influence of family size, environmental concern, cadre status, and policy propaganda is stable; the influence of social norms gradually strengthens; and the influence of risk attitude weakens. Although household income and the proportion of agricultural income have no significant effect, their influence gradually increases and changes positively and significantly over time; hence, they may become important factors in the future. Our results provide important policy implications for policymakers and agricultural managers to develop appropriate strategies to reduce the usage of chemical fertilizers in China.

Keywords: environment-friendly; farmers' behavior; fertilizer consumption; influencing factors; meta-analysis; China

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1. Introduction

As an important input in agricultural production, chemical fertilizers have greatly improved food production and ensured food security. However, with its continued and increasing usage, the overuse of chemical fertilizer has also caused several environmental problems [1] such as water pollution [2] and soil compaction [3]; these environmental problems caused by the overuse of chemical fertilizer have become particularly serious in developing countries. China's chemical fertilizer use has gradually declined after reaching a historic peak in 2015. In 2020, China used 52.507 million tons of chemical fertilizer in agricultural production, nearly 0.3 tons per ha (this data is derived from the Statistical Yearbook of China in 2021), but still exceeds the world average. Long-term excessive application of chemical fertilizers leads to a decline in soil fertility. However, to improve or maintain agricultural yield, a substantial amount of chemical fertilizers has generally been applied, forming a vicious circle and deteriorating the agricultural environment [4]. The traditional application of chemical fertilizer not only hinders the sustainable development of agriculture and rural areas in China but may also cause a serious concern to food safety. To promote the reduction and efficiency of chemical fertilizer use, and reduce agricultural environmental pollution in the country, China's Ministry of Agriculture formulated the Action Plan for Zero Growth of chemical fertilizer use by 2020 in 2015. Notably, by the end of 2020, the utilization rate of chemical fertilizer in China's three major food crops rice, wheat, and corn was still less than 50%.

China has a large population and a large demand for grain. As the "grain" of the grain, a significant reduction in the application rate of chemical fertilizer may lead to a reduction in agricultural output and threaten food security [5]. In addition, China's agricultural production is mainly managed by smallholder farmers. It is neither possible nor realistic to completely rely on the government to supervise the fertilizer application behavior of the numerous farmers. Rather, analyzing which factors affect farmers' fertilizer application behavior can help policymakers design appropriate strategies to promote the decrease in fertilizer use and the increase in fertilizer application efficiency. Studies show that farmers having a lack of scientific knowledge of fertilizer application often leads to inappropriate application behaviors to improve production yield and increase economic benefits. In addition, with urbanization, the rural labor force continuously transfers to cities [6], Chinese farmers are clearly aging, and their dependence on the usage of traditional chemical fertilizers continues to increase; these structural forces have inhibited efforts to reduce fertilizer use and improve fertilizer application efficiency. There is an urgent need to understand how farmers' environment-friendly fertilization behavior (FEFB) can be promoted in China to achieve chemical fertilizer reduction and efficiency improvement [7].

Many scholars have empirically examined which factors affect FEFB, and revealed that farmers' individual, family, planting, and cognitive characteristics, and external conditions may affect FEFB. However, the obvious differences and conflicting findings in previous studies in terms of methodology, factors considered, and results, mean that the policy direction remains unclear. First, regarding farmers' individual characteristics, studies have found that asking farmers to change the behavior of fertilization application is more difficult as farmers' age increases and the excessive application of chemical fertilizers becomes more concerning [8]. This finding may be contradicted by the findings of Zheng et al. [9], who found that the older the farmers, the deeper the family connections. To pass the farmland as property to their descendants, Chinese farmers are more willing and inclined to implement environmentally friendly fertilization behavior to protect the farmland.

Second, on family characteristics, studies have found that part-time farmers, whose major income is from non-agricultural production activities, may be more inclined to use chemical fertilizer instead of labor input, resulting in the excessive application of chemical fertilizer [10]. However, previous studies also show that migrant farmers are more likely to have green agricultural production knowledge and skills, and thus, promote FEFB [11].

Third, regarding farmers' planting characteristics, farmers with a larger scale of production tend to have a higher level of farm mechanization and, thereby, are more willing to implement environment-friendly fertilization behavior [12]. However, Wu et al. [13] found that farm size had no effect on FEFB.

Finally, regarding external factors, previous studies have suggested that technical guidance on fertilization can help farmers reduce excessive application of chemical fertilizers and promote FEFB [14]. However, some studies also found that it is not easy for Chinese farmers to adopt environmentally friendly fertilization technology; hence, technical guidance on fertilization may not affect FEFB [15].

From the literature review, we found that there are rich empirical studies to investigate the potential factors that may affect FEFB in China; however, the mixed results among different studies also bring great challenges to the theoretical construction and policy formulation regarding FEFB. Specifically, simply analyzing the factors affecting farmers' fertilization behavior through primary research (i.e., using field surveys) may not be enough to reconcile the differences between existing studies. Rather, we need to systematically collect, combine, and analyze existing studies to draw a more robust conclusion. To address this knowledge gap, this study conducts a meta-analysis to quantitatively synthesize the studies and investigate the following two research questions: (1) What are the key factors that may generally affect FEFB in China? (2) How does the influence of various factors change over time? The results of this study provide a more conclusive characterization of the relationship between FEFB and important variables that may affect the relationship.

2. Methodology

Meta-analysis can be regarded as a quantitative literature review method using large samples, which can integrate the results of multiple independent studies, assess the robustness of findings in an area, identify and resolve conflicting findings in past research, and then draw more clarity and robust conclusions for scholars and practitioners [16,17]. Meta-analysis was initially widely used in the field of medicine. In recent years, it has been gradually applied in humanities, social sciences, and natural sciences, among other research areas. Generally speaking, meta-analysis methods can be divided into the calculation of comprehensive effect size, publication bias test and correction, cumulative meta-analysis, and other processes according to their analysis order [18].

2.1. Calculation of Comprehensive Effect Size

The purpose of comprehensive effect size calculation is to integrate the results of different studies and conduct statistical tests on whether a variable is significant under large samples. However, the units for the same variable (such as household income) and research methods may differ across studies; the results of different studies cannot be directly integrated. Thus, the results for the same variable from different studies are converted into an integrated common measure, called the effect size. Following Nelson [19], we chose the standardized mean difference Cohen's d as the effect size as follows:

$$EF = \frac{\overline{X_1} - \overline{X_2}}{S_{within}} \tag{1}$$

$$S_{within}^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \tag{2}$$

where EF is the effect size, Cohen's d, $\overline{X}_1$ and $\overline{X}_2$ are the means of the experimental and control groups, respectively, S_{within} is the standard deviation within the group, and n_1 and n_2 are the sample sizes of experimental and control groups, respectively. Through these measures, we sought to have a dimensionless measure of the quantitative research results, and thereby compare results across studies and calculate the comprehensive effect size. See Cooper et al. [20] for how different quantitative research results can be translated into Cohen's d.

While calculating the comprehensive effect size, the same influencing factors may appear in different studies; this may lead to heterogeneity among the effect sizes in different studies due to differences in research methods and assignment methods. To calculate the comprehensive effect size considering this, we followed Field [21] and selected the Q statistic to test the heterogeneity. If there was heterogeneity, we used the random effect model to estimate the comprehensive effect size; otherwise, we used the fixed effect model. Note that the precision of the same variable in various studies is different. If all studies have the same weight in the calculation of the comprehensive effect size, it may bias the calculation results. Therefore, we calculated the composite effect size using the inverse of the variance as the weight:

$$\hat{\theta}_k = \theta = \mu_k + \sigma_k \varepsilon_k \tag{3}$$

$$w_k = \frac{1}{\hat{\sigma}_k^2 + \hat{\tau}^2} \tag{4}$$

$$Q = \sum_{k=1}^{k} w_k \left(\hat{\theta}_k - \frac{\sum_{k=1}^{k} w_k \hat{\theta}_k}{\sum_{k=1}^{k} w_k}\right)^2 \tag{5}$$

$$\overline{EF} = \frac{\sum_{k=1}^{k} w_k EF_k}{\sum_{k=1}^{k} w_k} \tag{6}$$

where $\hat{\theta}_k$ is the estimated effect size, θ is the true effect size, μ_k is the effect between groups, σ_k is the standard deviation of the effect size, ε_k is the measurement error. w_k is the inverse variance weight, $\hat{\sigma}_k^2$ is the estimated variance of the effect size, $\hat{\tau}^2$ is the estimated variance between groups. Q is the Q statistic of heterogeneity test, and $\overline{EF}$ is the comprehensive effect size.

2.2. Publication Bias Test and Correction

Publication bias refers to the idea that articles with significant research results are more likely to be published than those with insignificant research results, especially when the sample size is relatively small [22]. Since insignificant results have not been published or are rarely published, this part of the data may not be collected in this study, and thus, the results of the comprehensive effect size may be biased. To address this, we follow Moreno et al. [23] and use the nonparametric method of an inverted funnel plot to test publication bias; if there is publication bias, Trim and Fill's nonparametric method is used to correct it [24].

2.3. Cumulative Meta-Analysis

Cumulative meta-analysis is used to investigate how the trend of the effect size of these influencing factors (hereafter, influence trend) changes over time. Cumulative meta-analysis involves arranging the collected data in chronological order, integrating the effect size in turn, and analyzing the changes in the influence trend of a certain factor on FEFB over time. Considering the difference between the acquisition time of data and the publication times of different studies, we used the sampling year in each study as the time record.

3. Data Sources and Variable Selection

3.1. Data Sources

All data are derived from published journal papers. Studies published in Chinese were retrieved from the China National Knowledge Infrastructure (CNKI) website, while English ones were retrieved from the Web of Science. The keywords retrieved were: Fertilization(s), Behavior, Willingness, (Influence) Factor(s), Decision making, Farmer(s), Overuse, Safety, Environment, and Environment-friendly etc., and their combinations of keywords. To consider research quality, the selected studies published in Chinese are sourced from CSSCI journals and those published in English are from SCI or SSCI journals. A total of 3238 articles were retrieved in the initial search. A total of 1846 duplicate articles were deleted. A total of 1211 articles were eliminated by browsing the title and reading the abstract, and 181 articles were left. Finally, 64 articles were selected according to the following criteria: (1) the original language is Chinese or English; (2) study area is in China; (3) the study selected must be a primary (quantitative) study on the farmer's behavior or willingness of environment-friendly fertilization; Specifically, the selected studies must investigate the potential factors that may affect FEFB; (4) Cohen's d effect size is explicitly mentioned or there is enough information to compute it and provides a clear effective sample size; and (5) to ensure the independence between studies, studies with the same data source but published in different journals were selected only with the one that has more detailed quantitative information.

3.2. Variable Description

In this study, FEFB refers to farmers' fertilization behavior/willingness to address agricultural environmental pollution, including reducing the amount and frequency of traditional chemical fertilizer application; willingness/behaviors to adopt environment-friendly fertilization techniques; willingness/behaviors to replace chemical fertilizer with organic fertilizer; and improving chemical fertilizer application efficiency.

Considering the rule of thumb that the number of single effect sizes should not be less than 5 in the process of effect size integration, 24 variables in 5 categories were selected in this study. Specifically, these categories include farmers' individual, family, planting, and cognitive characteristics, and external conditions. The definition and measurement methods of explanatory variables are listed in Table 1.

Table 1. Explanatory variables and measurement methods.

Explanatory Variables	Definition	Measurement Method
Individual characteristics		
Gender	Gender of household head	Binary variables
Age	Age of household head	Continuous variables or ordinal categorical variables
Education	Education level of head of household	Continuous variables, ordinal categorical variables or binary variables
Health status	Health status of household heads	Binary variables or ordinal categorical variables
Risk attitude	Risk preference, risk neutral, risk aversion	Continuous variables, ordinal categorical variables or binary variables
Family characteristics		
Family size	Total family population	Continuous variables
Agricultural labor force	Number of family agricultural labor force	Continuous variables
Household income	Family annual total income	Continuous variables or ordinal categorical variables
Proportion of agricultural income	Ratio of agricultural income to household annual total income	Continuous variables or ordinal categorical variables
Part-time farming	Number of workforces engaged in non-agricultural activities	Continuous variables, ordinal categorical variables or binary variables
Planting characteristics		
Farm size	Total crop planting area	Continuous variables or ordinal categorical variables
Planting years	Years of agricultural production	Continuous variables
Land fragmentation	Number of planting plots	Continuous variables or ordinal categorical variables
Land quality	The degree of soil fertility	Continuous variables, ordinal categorical variables or binary variables
Cognitive characteristics		
Environmental concern	Degree of concern for the environment	Ordinal categorical variables
Environmental cognition	Cognition of environmental pollution	Continuous variables, ordinal categorical variables or binary variables
Social norms	Perception and recognition of social norms	Ordinal categorical variables
External condition		
Agricultural cooperative	Whether to join agricultural cooperative	Binary variables
Cadre status	Whether there are village cadres in the family	Binary variables
Technical training	Number of technical training sessions	Continuous variables or ordinal categorical variables
Policy propaganda	The degree of government policy propaganda	Ordinal categorical variables or binary variables
Government subsidies	Government agricultural subsidies	Continuous variables, ordinal categorical variables or binary variables
Technical guidance	Whether it is guided by professional and technical personnel	Ordinal categorical variables or binary variables
Social network	The frequency of communication with relatives and neighbors	Continuous variables, ordinal categorical variables or binary variables

4. Results and Discussion

4.1. Calculation of Comprehensive Effect Size

The comprehensive effect size of the influencing factors and the results of significance, heterogeneity, and publication bias tests are shown in Table 2.

Table 2. Comprehensive effect sizes and tests.

Variables	$\overline{EF}$	SE	Q	P_Q	τ^2	Z_B	P_B	n	N
Gender	0.0259 **	0.0105	18.1662	0.9219	0.0005	1.8476	0.0756	29	37,657
Age	−0.0169	0.0243	484.2097	0.0001	0.0069	−1.5863	0.1172	72	141,462
Education	−0.0010	0.0229	249.5609	0.0001	0.0055	−0.3203	0.7496	81	145,062
Health status	0.0881 *	0.0498	572.3275	0.0001	0.0116	−2.5787	0.0275	12	91,138
Risk attitude	−0.1019 **	0.0425	41.6546	0.0004	0.0097	0.8071	0.4322	17	11,942
Family size	0.0558 ***	0.0051	13.7533	0.4682	0.0004	−1.1073	0.2882	15	87,500
Agricultural labor force	−0.0041	0.0165	67.6805	0.0072	0.0017	0.7973	0.4299	43	36,714
Household income	0.0341	0.0372	69.7600	0.0001	0.0079	0.9099	0.3737	22	12,732
Proportion of agricultural income	0.0322	0.0654	24.1191	0.0196	0.0163	1.3133	0.2158	13	5464
Part-time farming	−0.0138	0.0517	68.7650	0.0001	0.0135	1.3579	0.1922	19	12,619
Farm size	−0.0391 *	0.0228	297.3803	0.0001	0.0002	1.3627	0.1793	50	34,887
Planting years	0.0645	0.0618	98.4930	0.0001	0.0192	1.3009	0.2225	12	9613
Land fragmentation	0.0584	0.0441	149.1745	0.0001	0.0110	−0.2326	0.8190	18	14,782
Land quality	0.0221	0.0373	127.7170	0.0001	0.0096	−0.4475	0.6581	29	21,141
Environmental concern	0.1420 ***	0.0437	3.2244	0.9937	0.0071	−1.1395	0.2787	13	6475
Environmental cognition	0.1370 *	0.0722	3.8930	0.9520	0.0222	2.1704	0.0581	11	8689
Social norms	0.1676 *	0.0983	1.6473	0.9491	0.0372	4.4456	0.0067	7	6491
Agricultural cooperative	0.0103	0.0656	200.8154	0.0001	0.0287	0.0059	0.9954	29	20,591
Cadre status	0.0943 ***	0.0245	11.7942	0.6945	0.0021	0.7905	0.4424	16	8036
Technical training	−0.0101	0.0345	56.2926	0.0005	0.0064	2.0393	0.0521	27	24,561
Policy propaganda	0.1756 ***	0.0451	7.5441	0.8720	0.0146	−0.1451	0.8871	14	5598
Government subsidies	0.1363 **	0.0538	46.7072	0.0006	0.0140	3.0655	0.0064	21	12,238
Technical guidance	0.0280	0.0816	6.8539	0.4442	0.0312	2.0236	0.0895	8	13,089
Social network	−0.0220	0.0712	48.0052	0.0001	0.0255	0.7966	0.4400	15	5586

Q is the Q statistic of heterogeneity test, P_Q is the P value of significance of heterogeneity test, τ^2 is the variance between groups, Z_B is the Z-statistic of publication bias test, P_B is P value of significance test of publication bias, n is the number of effect size, and N is the total sample size. ***, ** and * represent significant level at 1%, 5% and 10%, respectively.

Our results show that gender, health status, risk attitude, family size, farm size, environmental concern, environmental cognition, social norms, cadre status, policy propaganda, and government subsidies significantly affect FEFB. Notably, publication bias was found in six variables, including gender, health status, environmental cognition, technical training, government subsidies, and technical guidance; these were corrected with Trim and Fill's non-parametric methods (see Table 3 and Figure 1).

Table 3. Publication bias correction.

Variables	$\overline{EF}$	SE	Q	P_Q	τ^2	Direction	N_S	SE_N
Gender	0.0249 *	0.0105	25.5937	0.7813	0.0005	Left	4	3.5815
Health status	0.1153 **	0.0474	572.8488	0.0001	0.0114	Right	3	2.3406
Environmental cognition	0.1036	0.0763	6.8475	0.9098	0.0276	Left	3	2.2327
Technical training	−0.0407	0.0332	77.3997	0.0001	0.0062	Left	10	3.2855
Government subsidies	0.0610	0.0589	63.8818	0.0001	0.0206	Left	7	2.9542
Technical guidance	−0.0387	0.0625	13.4182	0.2012	0.0218	Left	3	1.8667

N_S is the number of Trim and Fill effect size with non-parametric correction, and SE_N is a standard error of N_S. ** and * represent significant level at 5% and 10%.

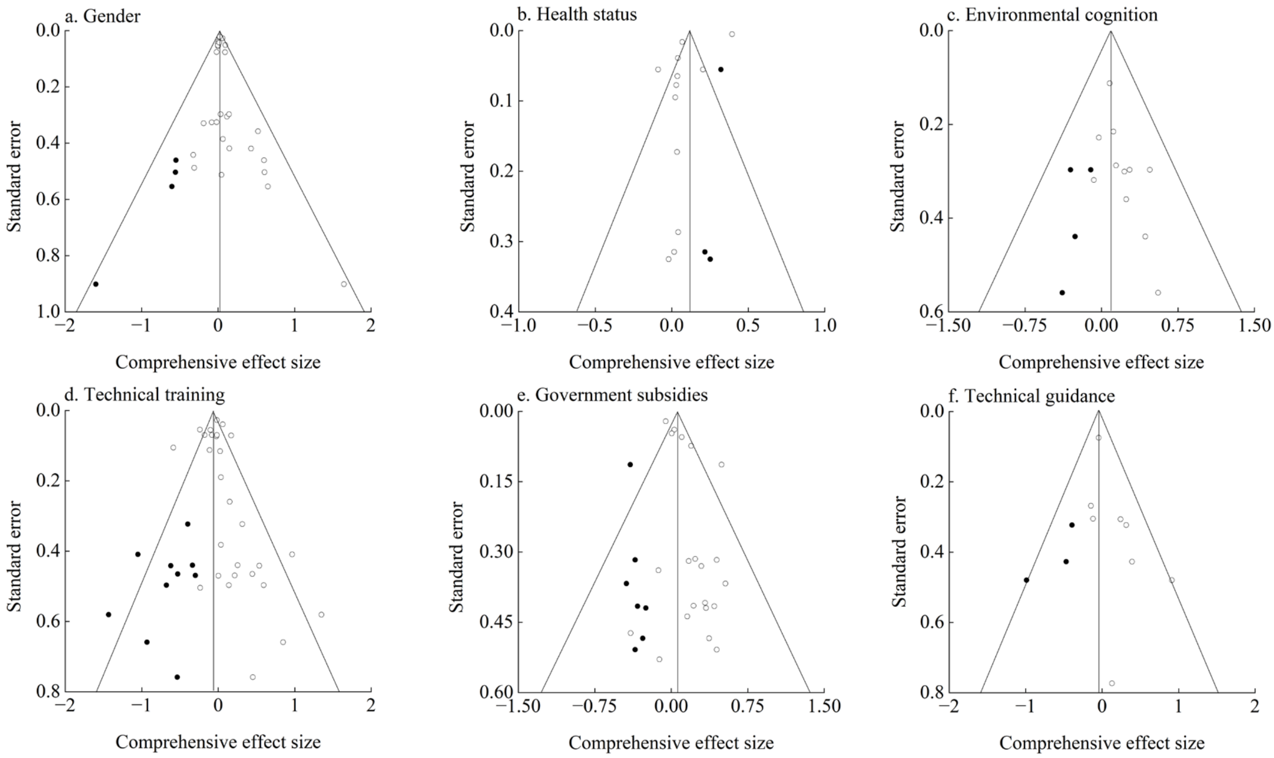

Figure 1. Funnel plot of publication bias correction. Hollow circles represent the effect sizes of previous studies, and solid circles represent non-parametric imputation values.

4.1.1. Individual Characteristics

In this category, except gender, health status, and risk attitude, the other variables representing individual characteristics have no significant effect. Specifically, male farmers are significantly more willing to adopt environmentally friendly fertilization behavior than female farmers, consistent with the findings of Liu et al. [8]. This may be because women in rural China tend to run the household and have a relatively weak risk tolerance. The effects and benefits of environmentally friendly fertilization behavior in agricultural production are uncertain, resulting in low acceptance of these behaviors among women. Health status has a significant positive impact on FEFB, consistent with the findings of Abebe and Debebe [25]. Moreover, those farmers with better health conditions can provide higher labor inputs and are more likely to adopt environmentally friendly fertilization behavior. Moreover, risk attitude has a significant negative impact on FEFB. This may be due to the reason that smallholder farmers in China generally tend to be risk-averse; a higher degree of risk aversion lowers the possibility of implementing FEFB [26]. Smallholders also tend to overuse chemical fertilizers to maintain stable yields (and agricultural income). Interestingly, education level has no significant effect on FEFB, contrary to the findings of Wakeyo and Gardebroek [27], who found that more educated farmers are more likely to accept and learn environmentally friendly fertilization technology in Africa. However, in China, with urbanization, rural labor continues to migrate to urban areas and big cities and the education level of farmers in countryside is generally low; this reality may explain why the education level has no effect on FEFB. This also implies that the current education development in China is still unbalanced between urban and rural areas; thus, strengthening education in rural areas, especially vocational education, is crucial for farmers to adopt environmentally friendly fertilization.

4.1.2. Household Characteristics

Except family size, other variables in this category have no significant effect on FEFB. Contrary to the findings of Akpan and Aya [28], we found that family size has a significant and positive impact on FEFB. This may be because, for Chinese smallholders, the more family members they have, the more income they need to make a living. The traditional fertilization method with frequent applications has a high cost and causes a small yield increase [29]; this may increase farmers' willingness to try environmentally friendly fertilization and best management practices to reduce cost as well as increase yield. Agricultural labor force has no significant impact on FEFB. This is inconsistent with the findings of Ragasa and Chapoto [30], who noted that traditional chemical fertilizer application increases with the agricultural labor force. Interestingly, China's agricultural production activities are often family-oriented and the production decisions are usually decided by the household head. This may be why the numbers of the agricultural labor force have no significant effect on FEFB in China. Our results also found that household income, a proportion of agricultural income, and part-time farming have no significant impact on FEFB, which is inconsistent with the findings of Zhang et al. [10] and Ma et al. [31]. With the rapid urbanization in China, farmers commonly have part-time jobs and the sources of income have been diversified. Since agricultural income is not the main source of household income, the increase in total household income mainly depends on the increase in non-agricultural income. Thus, when agricultural production has a relatively small income contribution, a farming household is less likely to invest more funds in environment-friendly fertilization. This conjecture may also explain why household income, a proportion of agricultural income, and part-time farming have no effects on FEFB in China.

4.1.3. Planting Characteristics

In this category, we found that only farm size has a significant effect on FEFB. While Ju et al. [12] found that those who have larger farmlands would be more willing to adopt environmentally friendly fertilization behavior, results of our meta-analysis revealed that farm size had a significant negative impact on FEFB. This may be because, on the one hand, the risks from adopting environmentally friendly fertilizer use increase with farm size. On the other hand, the low cost of traditional chemical fertilizer application means that farmers are less likely to adopt environmentally friendly fertilization behavior given its uncertainty on production yield. Planting years have no significant effect on FEFB. This is inconsistent with the findings from Pandey and Diwan [32] that the number of planting years can enrich farmers' planting experience and significantly affect farmers' fertilizer application decisions. However, the farming choices of smallholder farmers in China are often passive. Specifically, with an increase in planting years, the inherent planting habits and practices of farmland management are more difficult to change; this may explain why the planting years have no effect on FEFB. Meanwhile, although Chi et al. [33] found that land fragmentation significantly hinders FEFB, our results show that there is no significant effect of land fragmentation on FEFB. This may be because, since China's reform and opening up, the land distribution policy based on equity has led to the problem of cultivated land fragmentation. Moreover, with the confirmation of land rights in recent years, this problem has been aggravated. This may "force" farmers to get used to the agricultural production on fragmented lands, and thus will not affect their fertilization behavior. Finally, similar to He et al. [34], we found that land quality has no significant effect on FEFB.

4.1.4. Cognitive Characteristics

In this category, both factors of environmental concern and social norms could effectively promote FEFB. Consistent with Ma et al. [35], farmers with a higher degree of environmental concern have a stronger awareness of environmental protection and are more concerned about environmental pollution caused by traditional fertilization methods. In addition, environmental pollution is closely related to farmers' health. Hence, farmers may pay more attention to environmental problems and implement environmentally friendly fertilization behavior to protect their clean-living environment. Regarding social norms, farmers' behavior in China's agricultural society is inevitably affected by group behavior given the family-centered nature of farming in China. When a farmer's community encourages the implementation of environmentally friendly fertilization behavior, the farmer will also be inclined to implement these behaviors to integrate into the community; this is consistent with evidence from Cui and Liu [36]. Additionally, contrary to Baumgart-Getz et al. [37] who showed that environmental cognition significantly promoted FEFB, our results revealed that there is no significant relationship between environmental cognition and FEFB. Unlike the modern farm systems and large-scale production in developed countries, China has a large number of aging smallholders. Hence, it is not easy for Chinese farmers to avoid the free-riding phenomenon and benefit from others' environmentally friendly management practices. This phenomenon also makes it difficult to transform farmers' environmental cognition into specific actions. Thus, our result may imply that the concepts of environmental cognition and environmental concern are quite different for Chinese farmers and may not be highly correlated. This may also explain why only the factor of environmental concern could promote FEFB in China. This finding may suggest that the government's agricultural environmental governance policies should aim at not only improving farmers' environmental awareness but also their concern for the environment to achieve policy effectiveness.

4.1.5. External Conditions

Except for cadre status and policy propaganda, other variables had no significant effect on FEFB in this category. Cadre status has a significant positive impact on FEFB. As the propagandizers of government policy, village cadres are more willing to follow the government's promotion, have a deep understanding of environmentally friendly fertilization behavior, and can better realize the benefits of FEFB. The factor of policy propaganda has a significant positive impact on FEFB., which is consistent with views of Emmanuel et al. [38]. This result also indicates to some extent that the government should strengthen policy propaganda and then promote the implementation of FEFB. Meanwhile, differing from Manda et al. [39] who found that joining cooperatives can promote the implementation of FEFB, we found that this factor has no significant effect on FEFB in China. While most smallholder farmers in China join cooperatives, many cooperatives have no actual constraint on farmers' behavior [40]. Moreover, government subsidies have no significant impact on FEFB. This finding differs from evidence by Guo et al. [41] that government agricultural subsidies can significantly reduce the amount of traditional chemical fertilizers and promote FEFB. One possible reason is that, given the large number of smallholder farmers in China, the government cannot afford the subsidies. Rather, subsidies may be given to specific farmers in pilot projects to demonstrate the environmental benefits of FEFB. Finally, technical training and guidance have no significant impact on FEFB, which differs from Rahman and Connor [42] who find these two factors have positive effects on FEFB. This may be due to the reason that environmentally friendly fertilization technology requires farmers to have a certain level of education. However, Chinese farmers are aging significantly and generally have a low level of education [43]. Furthermore, their acceptance of new things is low. This may also suggest the importance of providing agricultural vocational education for farmers.

4.2. Cumulative Meta-Analysis

Cumulative meta-analysis was used to analyze the influence trend of the key influencing factors on FEFB over time. As the variables with publication bias have been corrected by non-parametric methods, these variables are not further analyzed here. The results are shown in Figures 2–6.

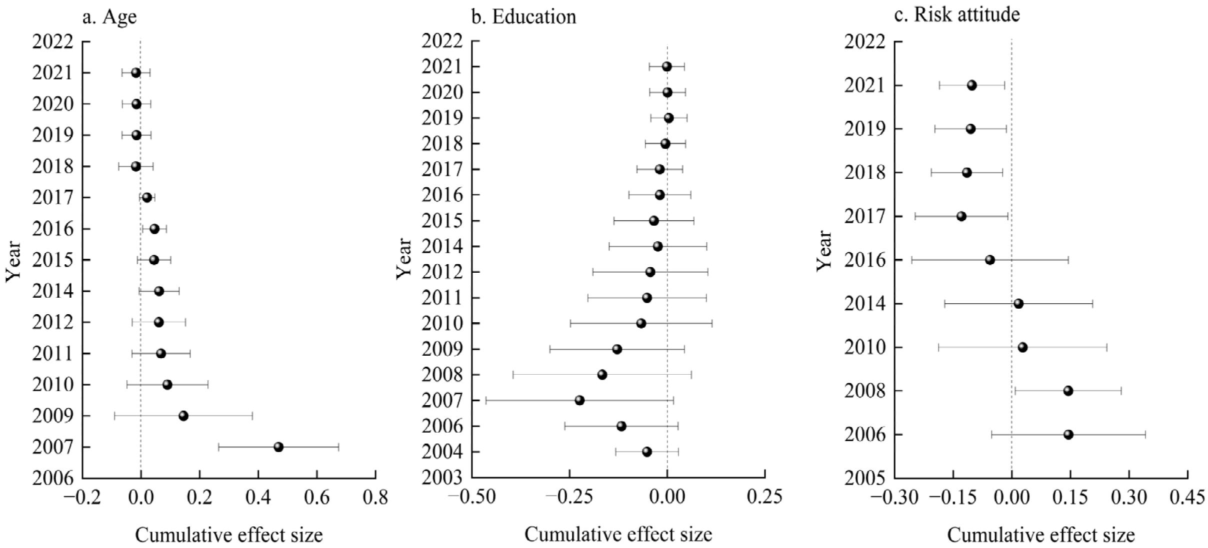

Figure 2. Cumulative meta-analysis trend (individual characteristics).

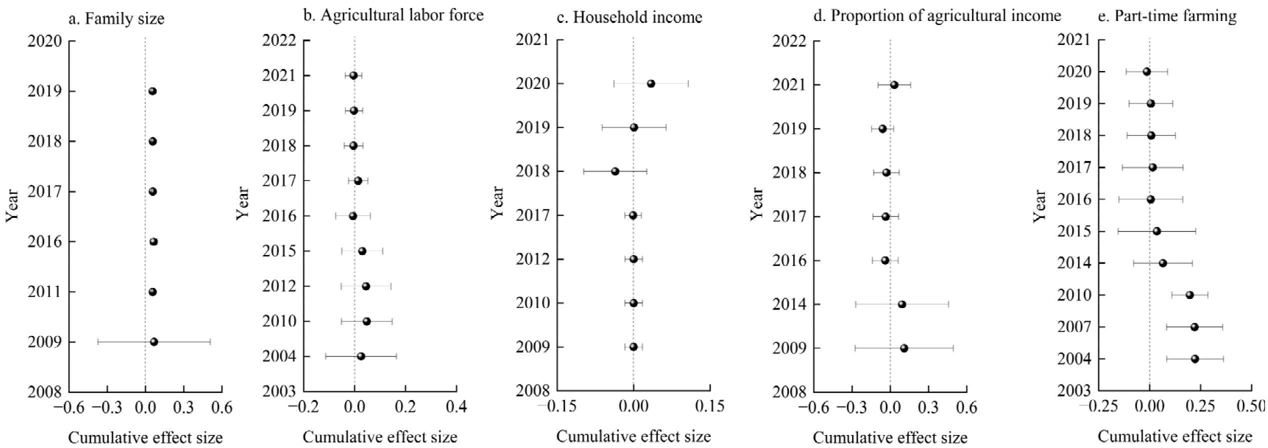

Figure 3. Cumulative meta-analysis trend (household characteristics).

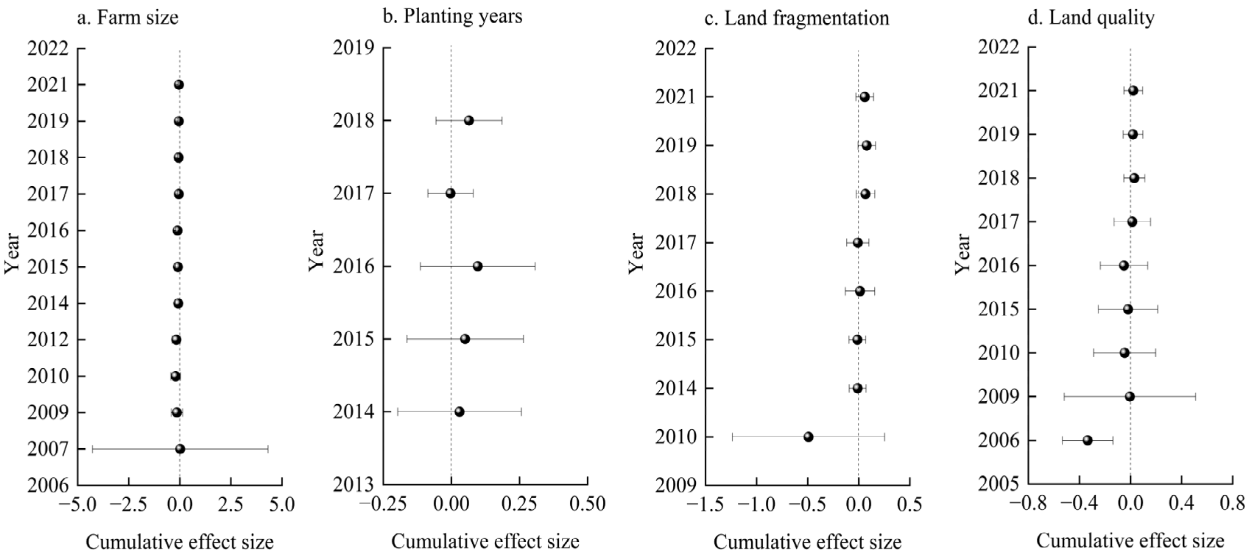

Figure 4. Cumulative meta-analysis trend (planting characteristics).

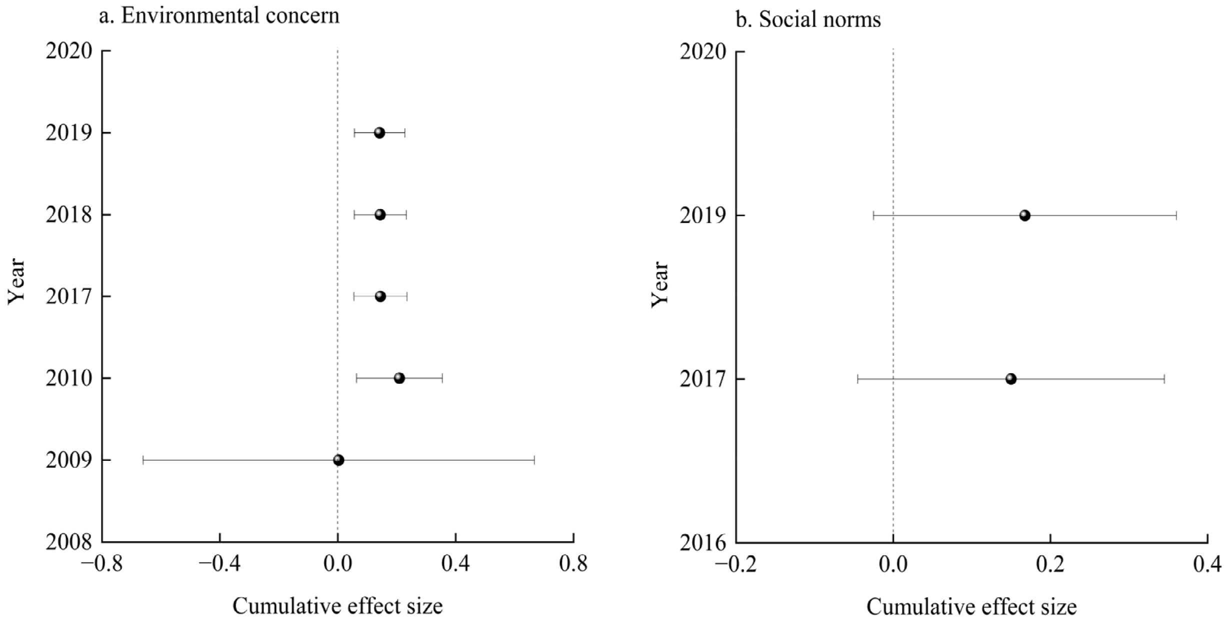

Figure 5. Cumulative meta-analysis trend (cognitive characteristics).

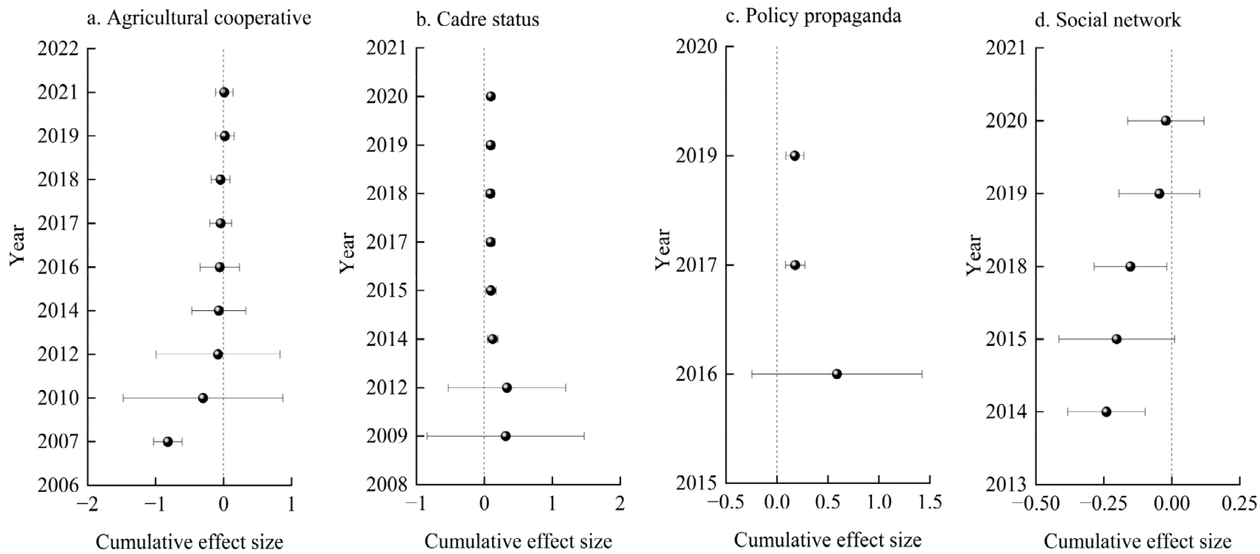

Figure 6. Cumulative meta-analysis trend (external conditions). The missing year indicates that there is no corresponding effect size for that year, the solid circle of the line segment in the figure represents the cumulative effect size, and the left and right sides are 95% confidence intervals.

4.2.1. Individual Characteristics

Over time, the influence of age on FEFB changed from significant to insignificant (see Figure 2a) and the trend is relatively stable. Together, this may be related to the more obvious aging of Chinese society and the generally older age of farmers in China in recent years [44]. Importantly, while the influence trend of education was not significant after 2006, it changed from strong to weak. This may be because, before China completely abolished the agricultural tax in 2006, the burden of farming was heavy and farmers with a certain level of education were more inclined to go to cities to work; this led to farmland abandonment. After the abolition, as some farmers with a higher level of education returned to their hometowns, this negative impact gradually weakened and tended to be negligible. While risk attitude has a significant negative impact on FEFB, its impact has continued to weaken. This may be caused by the increase in farmers' non-agricultural income and their risk tolerance [8]. Consequently, with the promotion of rural revitalization in China and the further improvement of farmers' income levels, risk attitude may not be the key factor inhibiting FEFB in the future. This may also suggest that improving farmers' income can be a crucial area of policy intervention.

4.2.2. Household Characteristics

The factor of family size could significantly promote the FEFB, with the effect being relatively stable (see Figure 3). The agricultural labor force has a stable but non-significant effect on FEFB. This may be caused by the fact that most young and middle-aged rural laborers go out for work and the number of families staying in villages for farming is generally small [45]. Household income has no significant effect on FEFB, but gradually exhibits a positive and significant trend with time. This variable may be one of the important factors in promoting FEFB in the future and highlights the importance of promoting farmers' income. The proportion of agricultural income had no significant effect on FEFB but gradually shows a positive and significant trend. As farmers' incomes improve, the proportion of agricultural income is likely to decrease. In addition, part-time farming had a significant positive impact on FEFB before 2014; however, its impact declined, becoming negligible over time. This is consistent with China's economic development practice. In the early stages of development, rural China had an inward-oriented development model. Specifically, farmers made up for the shortage of agricultural income through non-agricultural income and increased agricultural input objectively [46]; this was a livelihood mode of external supplement to internal income. However, with urbanization and economic development, this agricultural development mode has an outward focus [47]. Specifically, farmers have relied on both agricultural and non-agricultural incomes to buy houses in cities and towns to meet their livelihood strategies of urbanization. Therefore, while part-time farming may have promoted FEFB in the early stage, its influence has gradually weakened in recent years.

4.2.3. Planting Characteristics

The negative impact of farm size on FEFB remained stable (significant at a 90% confidence interval, see Figure 4). Contrary to farm systems in western developed countries, the agricultural industry in China is dominated by smallholder farm management and non-mechanized production operations. The expansion of farm size significantly increases labor input, which decreases the possibility of adopting FEFB [48]. However, our results also show that planting years, land fragmentation, and land quality had no significant effect on FEFB, and overall, their influence was relatively stable over time.

4.2.4. Cognitive Characteristics

Results in Figure 5 show that environmental concern has significantly promoted FEFB, with its influence trend being relatively stable. Specifically, the higher the degree of farmers' environmental concern, the more they can realize the adverse consequences of long-term environmental pollution. This also implies the government should inform farmers of the current situation of agricultural environmental pollution and its close relationship with farmers themselves to raise their environmental concerns and promote FEFB. Interestingly, the positive impact of social norms on FEFB is increasing. While this variable is only significant at the 10% level of significance in Table 2, it may be an important factor affecting FEFB in the future and become the focus of agricultural environmental governance, given the family-centered nature of Chinese farming.

4.2.5. External Conditions

In this category, the decision to join cooperatives has no significant effect on FEFB and the trend is relatively stable. This indicates that the government should further standardize the operation of agricultural cooperatives to a certain extent [49]. Notably, the promotion effect of cadre status on FEFB became significant and relatively stable since 2014 (see Figure 6b). This may be because China launched a poverty alleviation program at the end of 2013. Consequently, village cadres across the vast rural areas of China were being professionalized, administrated, and regularized [50]. This may have restrained the unreasonable fertilization behavior of farmers with cadre status. Moreover, it may have also strengthened the regularization management in rural areas and even included village cadres in the official civil service team; this should be more conducive to FEFB. Moreover, policy propaganda has also shown the trend of a significant positive and stable effect on FEFB over time. Interestingly, the influence of social networks on FEFB gradually changed from a significantly negative to a non-significant level. In line with this trend, it may change to a significantly positive level in the future; this may indicate that communication and connections between farmers, and their relatives and neighbors are conducive to the diffusion of environment-friendly fertilization knowledge and technology [51]. This result may imply that using social networking in rural areas to promote FEFB could increase policy effectiveness.

5. Conclusions and Policy Recommendations

In this study, we systematically collect, combine, and analyze existing research regarding FEFB in China using a meta-analysis approach to investigate and identify the key factors that may affect FEFB in China and how their influence changed over time. The important findings are outlined below.

Firstly, our meta-analysis revealed that gender, health status, risk attitude, family size, farm size, environmental concern, social norms, cadre status, and policy propaganda significantly affected FEFB in China. Specifically, village cadre status, government policy propaganda, those who are male farmers, have good health conditions, larger family size, more concern for the environment, and strong social norms all had significant promotion effects on FEFB. However, results also show that factors related to high risk aversion and large farm size hindered FEFB.

Results of cumulative meta-analysis also revealed that the influence trend of the key factors that continuously and significantly affected FEFB including family size, environmental concern, cadre status, and policy propaganda remained stable. The influence of social norms strengthened; and the influence of risk attitude weakened. While the household income and proportion of agricultural income had no significant effect, their influence trend did change positively and significantly; hence, these may become important factors affecting FEFB in China in the future.

Essentially, our findings have provided several important policy implications of agricultural environmental governance in China in the future. Specifically, to improve farmers' environmental concern, the policy propaganda of environmentally friendly fertilization should be strengthened through TV, radio, internet, and other channels. Crucially, government policy may need to focus on increasing farmers' income through multiple channels and improve their ability to resist risks. Moreover, our results suggest that policymakers and environmental managers can leverage both the formal institutional arrangement of cadre status and the informal institutional arrangement of social norms to promote the FEFB, which may greatly improve policy effectiveness. In other words, this finding also highlights that balance should be maintained between the formal and informal institutions in rural China, rather than replacing the informal social norms with the regularized governance mechanism when promoting FEFB.

Finally, policymakers and agricultural managers should also pay more attention to factors that are currently non-significant but are exhibiting a significantly positive trend/change and may need to include these factors in the decision-making process of agricultural environmentally friendly fertilization and management practice in the future, as have been identified in this study. It is important to note that policymakers should not only consider the key factors that promote or inhibit FEFB but should also pay attention on how their influence changes over time.

There are limitations in this study that can be further improved. For example, we did not separately analyze the comprehensive effect sizes of different study areas and methods of the selected primary research (i.e., conducting a heterogeneous analysis). Refinements such as these are intended for future research by the authors. Furthermore, based on the major findings of this study, there is a need to conduct a large-scale field survey to verify the conclusions of this paper in the future.

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