

## Article

# Exploratory Research on Overfertilization in Grain Production and Its Relationship with Financial Factors: Evidence from China

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**Abstract:** Although there have been many studies on the degree of overfertilization, there are few systematic comparative analyses on the degree of overfertilization of three major grain crops (wheat, rice, and maize) over a long time span in recent years. Whereas the studies of the influence of government efforts, individual characteristics of farmers, and economic factors on farmer's fertilization decision ignored the financial consideration of farmers. This study aims to systematically investigate the degree of overfertilization in the production of three major grain crops in 21 provinces of China from 2004 to 2018 by developing a panel-data model, and explores the impact of financial factors on overfertilization by applying Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation. The results showed an upward trend in overfertilization in the production of three grain crops from 2010 to 2018, although a decline between 2007 and 2009 may indicate that the financial crisis had a short-term impact on overfertilization. Overfertilization varied across regions, and chemical fertilizers were applied most excessively in wheat production in the Huang-Huai-Hai region and in maize in Southwest China. The analysis of financial factors showed that cash earnings from wheat and maize positively affected overfertilization, whereas cash cost and farmers' income had opposite effects. In fact, farmers value cash earnings and cash costs rather than the time value of money. In addition, the sensitivity and cautiousness of farmers regarding economic events may indicate that farmers have a certain degree of economic rationality regarding fertilizer input in several provinces, such as Anhui and Yunnan. The study provides necessary supplements to existing research on the influence factors of overfertilization and has implications for improving the design of fertilizer sales collection methods by the government and the financial service sector.



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**Keywords:** overfertilization; cash cost; cash earnings; DPI (per capita disposable income of rural residents)

## 1. Introduction

Nutrient pollution from agricultural practices not only seriously affects the increase of grain production and farmers' income, impedes sustainable land development as well as conservative agriculture development [1,2], but also is intimately linked to human health costs [3]. In fact, due to limited arable farmland and large population, large-scale chemical fertilizer was input to increase crop yields, which has become one of the most feasible approaches to meet the growing demand for grain in China [4]. However, use of chemical fertilizer significantly exceeded the economically optimal level (i.e., by 30–60%), which has made overfertilization continue to be a problem in Chinese grain production (wheat, maize, and rice) at both national and regional levels [5–9]. From 59.84 million tons in 2016 to 54.04 million tons in 2019, the amount of fertilizer used in China declined year by year [10]. Take 2017 as an example, even though the total amount of fertilizer used decreased by 5.5%

from 2016, which accounted for approximately 33% of the world's total consumption, the amount used per hectare of arable land was 1.86 times the internationally recognized safe upper limit [11].

Institutional constraints including perceived lack of government support impedes reducing the use of chemical fertilizer [12]. In China, a series of government support measures have been adopted to tackle the problem of overfertilization and related low nutrient-use efficiency. For example, the Chinese Ministry of Agriculture preliminarily issued guidelines regarding the recommended amount of mineral fertilizers to be applied to maize, wheat, and rice, based on soil analysis to guide farmers in scientifically applying fertilizers in 2003, and "regional formula and fertilization recommendations for the three major food crops of wheat, maize and rice (2013)" [13]. In addition, the Ministry of Finance and the Ministry of Agriculture have carried out the Agriculture "three subsidies" pilot plan in certain counties in five provinces since 2015, to support protection of the farmland productivity and food moderate scale management, reducing the dosage of chemical fertilizers, organic fertilizers, etc., which favor major grain growers, family farms, farmers' cooperatives, and other new types of business entities [14,15]. However, for small farmers, the main form of farmers in China, direct cash or other subsidies are still a long way off. Therefore, the government's efforts to solve the problem of overfertilization are not satisfactory. The fertilization decision makers are important participants in solving the problem of overfertilization in the future, rather than only the regulated. It is necessary to find out the main influencing factors of smallholders' fertilization decisions, which contribute to formulate more effective government support measures.

Friedman believes that investment demand depends on the yield of production and the cost of holding money [16]. In decisions related to soil conservation, smallholder farmers were more likely to adopt soil carbon enhancing technologies or Integrated Soil Fertility Management, which consists of fertilizers management as core components for maize and wheat when they positively perceived net benefits and higher income [17,18]. For sustainable land management planning aimed to relieve land degradation decision, maximizing short-term income and production gains or to minimize direct outlays and cash expenditures is still a major concern among farmers [19], considering that the ultimate goal of farmers is to obtain as much income as possible from crop cultivation [20–32]. Soil fertility management, sustainable soil planning, and other decisions are of great value in mitigating fertilizer excess and illustrate farmers' fertilization decisions from the side view. Therefore, benefits and costs may have a significant impact on overfertilization.

What's more, the price of products appears the most economically sensitive and a major external element when referring to benefits (income of the farmers and well-being) and cropping plan decisions behavior [33,34]. On the basis of the lack of market information and the extent to which smallholders are integrated into the market, grain price and sales volume as the most basic marketing information reflect the role of market in fertilization decision-making, which is particularly important for smallholders to make fertilization decisions [35,36].

Over the years, the investment source of rural households in China mainly relied on their own income accumulation rather than the capital market. Farmers pursue high income, low cost, and even high grain prices for the purpose of increasing income, whereas the increase of farmers' income is conducive to the increase of their investment in agriculture [37]. The current situation of farmers adapting away from agriculture is difficult to meet the higher labor demands in increasing fertilizer efficiency [18,38]. However, an increase in income (off-farm income) may be an important condition for fertilization decisions [17,38,39]. The permanent income hypothesis developed by the US economist M. Friedman argues that consumption depends not only on income, but also on property and the long-term income that consumers can expect, which is characterized by maintaining stability [40]. Taking the income of recent years as an important part of the permanent income meets the adaptive expectation. Compared to income, disposable income is a better proxy for farmer affluence, which can be used for household final consumption,

discretionary spending, and savings [10]. Moreover, disposable income has an advantage in representing retained earnings, so it is more conducive to the study of decision-making of agricultural investment such as fertilizer input.

Previous studies have mainly focused on the influence of government efforts including agricultural extension and regional industrial structure adjustment etc., individual characteristics of farmers, some economic factors such as sales of agricultural products, farmers' income sources, and subsidies for organic fertilizers on farmer's fertilization decision, but ignored the financial consideration of farmers [8,11,21,23,29,30,41–56]. This study aims to demonstrate the characteristics of overfertilization in three major grain crops production in China from 2004 to 2018, and to unravel the financial causes of overfertilization in different types of grain production. Specifically, first the translog function estimation method is adopted to evaluate the degree of overfertilization in the production of wheat, rice, and maize in 21 provinces, using panel-data from 2004 to 2018. Then this study adopted the Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation to determine the impacts of cash earnings, cash costs, and disposable income (DPI) on fertilizer application from the perspective of farmers' potential economic considerations i.e., to explore whether higher cash earnings, cash cost, farmers' income, grain price, or grain sales (liquidity of agricultural products) are linked to more severe overfertilization.

The development of precision fertilization techniques, the breeding of more efficient crop plants, and research into microbial nutrient cycling and education programs for farmers, adequate manufacturing, storage, and transportation were paid more attention in the EU and the US, but the financial consideration of farmers in making fertilization decisions was ignored [57]. Thus, the study may complement the existing successful experience and solutions of the EU and the US to improve fertilizer efficiency. This study found that the higher the cash cost of agricultural production materials, the lower level of overfertilization, which suggests that the factors such as grain price and the cost of agricultural production materials should be considered in the government's efforts to control overfertilization. For example, redesigning the price and payment terms for chemical fertilizer will make farmers rebalance the expenditure structure of chemical fertilizer and other expenditures such as agricultural machinery. Thus, the study results may provide reference for improving payment terms of agricultural materials (fertilizer) and information disclosure system of the grain sales process in agricultural products market, which will contribute to more rational fertilization decision making in grain production in China.

The remainder of this paper is organized as follows. First, after a literature review of the subject studied, we present the research design, including the empirical model, data collection, analytical method, and findings, based on an estimation of the overuse of chemical fertilizers in grain production and regression results of contributing factors for the overuse of chemical fertilizers. Finally, we discuss our findings, highlight the contributions and limitations of this research, and give suggestions for future studies.

## 2. Literature Review

### 2.1. Estimation of the Degree of Overuse of Chemical Fertilizers in Grain Production

Chemical fertilizers are essential for agricultural production. However, the overuse of chemical fertilizers has caused many environmental problems, such as soil acidification and compaction, as well as increased social costs [43,44,58–63]. In 2007, 10.6% of Chinese farmland had a soil organic matter content lower than 0.6%, and 52.6% of the total area was deficient in phosphorus, indicating widespread and serious soil deterioration [64]. This has prompted scholars to conduct research on the degree of overfertilization and its influencing factors so as to help with fertilizer control.

Scholars have used various methods to estimate the degree of overfertilization. In all estimation methods, the most direct one is to compare the actual amount of fertilizer used and the recommended (or optimal) amount [26,65]. In addition, the Urban–Rural Complex N Cycling prediction model and the DeNitrification–DeComposition model were used to

predict the specific amount of fertilizer applied based on farmland experiments, such as the detection of chemical fertilizer residue, and the principles of element circulation [66,67]. The input–output ratio of fertilizer and crops can be used to calculate the amount of fertilizer used, considering yield increase and optimal output [25,68–71]. More advanced methods for estimating the efficiency of fertilizer application include applying Cobb–Douglas production functions and stochastic frontier production function models that account for labor force, land, capital, mechanical input, and organic fertilizers [7,8,23,31,45,72,73]. Moreover, several studies have adopted the stochastic frontier production function and translog function to estimate the efficiency of fertilizer use in rice production in certain regions such as northeast China and Anhui Province [23,69,70]. Estimation results showed that the amount of fertilizer used in China’s grain production has exceeded its economic optimal amount, and it has remained serious in recent years [9]. Zhu found that excessive application of chemical fertilizers all existed in the production of wheat, maize, or rice, and on average the overuse rate was 50% during 1984–2000 [74]. A survey on the main maize area showed that the average excessive amount of fertilizers application is 156 kg/ha, accounting for 38.5% of the actual application amount in 2010 [8]. The overuse of chemical fertilizers reached 116.04% in wheat planting in the North China Plain in 2011 [7]. The average degree of overfertilization in maize production was 50.74%, while in wheat and rice production, the degree of overfertilization was relatively low, 27.26% and 24.67% respectively during 2004–2013 [9]. Estimating the degree of overfertilization lays a foundation for exploring ways to reduce the use of chemical fertilizers. However, previous studies mostly estimated the degree of overfertilization in a certain region or a certain type of grain, rarely make systematic and comparative studies on it of all major grain crops of recent years in whole China.

## *2.2. Economic Factors and Other Factors Influencing Overuse of Chemical Fertilizers in Grain Production*

Previous studies on factors influencing overuse of chemical fertilizers in grain production have mainly focused on government guidance, including agricultural extension and regional industrial structure adjustment (development policy), and on the individual characteristics of farmers, such as age, risk preference, individual experience, education level, and other psychological factors. Specifically, evidence from previous studies and practices has shown that governmental guidance may reduce fertilizer use [41,42,75]. However, many studies have shown that farmers are not willing to reduce fertilizer use, which may indicate the economic rationality of their decisions regarding fertilizer dosage [76–78]. The studies on economic factors have been limited to sales of agricultural products, farmers’ income sources, and subsidies for organic fertilizers [8,11,21,23,29,30,41–56]. Among them, some researchers exploring the influence of government subsidies, loans, and contra flows found that farmers try to assess inputs and outputs rationally [29,79,80]. Several studies found that subsidies increase fertilizer application by economically or semi-economically acting farmers, and subsidies have a significantly negative effect on the total factor substitution efficiency of chemical fertilizer input [80–84]. Farmers often lack confidence in China’s grain production subsidy policy because of insufficient subsidy intensity, and low subsidy accuracy has led to a certain gap between the effect of policy implementation and expectations [85,86]. Compared to subsidies, Chinese farmers are more conscious of the cost of and earnings from grain production than of subsidies [87,88]. However, most related studies have focused on grain price or fertilizer price, individual characteristics (age, education level) of farmers, and sources of income, instead of financial factors such as cost, earnings, and capital turnover [54,89,90]. Some studies have shown that rapid increase in the cost of planting has become an important factor hindering the growth of farmers’ income from grain crops [91]. Further study is needed to investigate the important impacts of cash flow-back, cash costs, and cash earnings on fertilizer use, since the cash costs are the largest proportion of grain production, which is more of a concern for farmers [92,93]. Fertilizer costs account for a high proportion (38.47%) of all cash costs [94]. However, in recent years, fertilizer costs have accounted for a lower and lower proportion of the total

cash cost of grain cultivation [95,96]. The rise in costs has mainly been driven by labor costs, machinery costs, land costs, and seed costs. In fact, the promotion of mechanization can reduce the cost of wheat, corn, and other food products [97]. There is a strong substitutional relationship between mechanical input and fertilizer input in production. That is, the higher the cash cost of grain production, the lower the fertilizer input [98]. Although reduction in fertilizer application has a significant negative impact on grain yield per unit area, it does not have a significant impact on net income per unit area [99].

In addition, farmers are more willing to invest in chemical fertilizers that provide rapid reflux of agricultural costs or have good cost-effectiveness [23–32,76]. This is closely linked to market reactions such as food prices and sales volumes. Output price support increases the income of participating smallholder farming households (maize farmers) by at least 12% [34]. In the previous studies, the influencing of the price of crops and credits for inputs and other incentive measures on farmers' decision-making were identified. Therefore, food prices and sales may have a positive impact on fertilizer excess.

Studies on sustainable land development, conservation agricultural practices, and soil fertility management have also taken into account the income and cost that farmers pay attention to when selecting programs similar to soil conservation, whereas studies on the same considerations of fertilization decision of farmers are rarely involved. The increase of farmers' income level is conducive to the increase of their investment in agriculture [37]. Fiscal compensation programs enhanced the overall effects of farmer households' participation in farmland conservation in less-favored and developing regions [100]. Households' incomes were closely related to their environmental awareness, but were not directly related to farmers' willingness to accept compensation from a paddy-land-to-dry-land program [101]. Q-methodology is used to divide 26 grain-planting farmers in the Huaihe Basin into three types based on their attitudes towards policy, land, livelihood, and planting plan. Family support type farmers were especially concerned about policies directly related to their economic income [102]. Fertilizer inputs and other production inputs are often heavily influenced by farmers' incomes [78]. High prices of chemical fertilizers are often barriers to intensive maize cultivation, especially for low-income farmers [103]. Specifically, some research findings indicate that there is substitution between off-farm transfer rates of the agricultural labor force and the use of fertilizers in agricultural production [24,31,104–106]. The above analysis is sufficient to illustrate the important role of income in farmers' fertilization decisions.

In summary, the existing literature has enriched understanding of the degree of overfertilization in China. However, most studies tended to focus on overfertilization at the local level rather than regional or national level. In addition, more attention has been paid to that effect of individual characteristics of farmers on overfertilization, but there have been no studies on cash flow factors. Therefore, this study adopted the translog function to evaluate the degree of overfertilization of all major grain crops nationwide and to explore the influence of cash flow considerations (cash cost and cash earnings) on farmers' fertilization decision by analyzing panel-data at the provincial level for wheat, maize, and rice.

### 3. Hypotheses, Materials, and Methods

#### 3.1. Hypotheses

Economic earnings are the ultimate goal of farmers' fertilizer use. Chinese farmers hope to reduce agricultural labor input and pursue maximum cash earnings in order to progress from meeting basic demands to a well-off life, which is in line with "life rationality" and economic rationality [107]. It has been found that the rice/fertilizer price ratio has a positive impact on fertilizer use, which further demonstrated farmers' economic rationality [53]. In addition, a study of a rice/wheat cropping system found that using chemical fertilizers with straw incorporation significantly enhanced rice yield by 9.3% in the 2016 [108]. The potential contribution of fertilizers to yield growth and earnings remains attractive to farmers. Cash earnings are an important form of economic earnings from

agricultural production; considering the rich experience of Chinese farmers in fertilizer application for the production of cash crops and their current situation with regard to income diversification, cash earnings might be more important to farmers than non-cash earnings because they account for a larger proportion of earnings [109]. The more cash farmers have earned in previous years, the more they tend to invest in fertilizers in order to obtain more cash earnings in the near future [110]. The intensification of crop production in arid regions and elsewhere has led to rapid changes in farmers' agricultural and livelihood systems [102]. In terms of cost, agricultural production decisions are based on labor requirements, specifically production activities are viewed as labor saving or traditional labor, which describes the different issues currently guiding production decisions [102]. Whether labor-saving or labor-as-usual, as young people shift to off-farm work, reducing labor requirements may become an issue that farmers will have to consider. In the case of small changes in the grain production input budget, farmers may prefer to use machinery to harvest crops to reduce their labor intensity, rather than increase fertilizer input [107]. Therefore, this study proposes the following hypotheses:

**Hypotheses 1 (H1).** *The higher the cash earnings, the higher the level of fertilizer use.*

**Hypotheses 2 (H2).** *The higher the cash cost, the lower the level of fertilizer use.*

Further, once grains are planted, grain price and yield determine farmers' earnings [96]. Farmers are extremely sensitive to grain prices when the yields are relatively stable. The grain price has an immense influence on the economic earnings of grain production and the use of chemical fertilizers [111,112]. Therefore, the higher the price of grain, the more the farmers are willing to invest in fertilizer use. To a certain extent, the sales volume and revenue of grain have shown farmers' responses to grain prices, which have a certain influence on the future fertilizer input in grain production in terms of return on investment [113]. Therefore, this study proposes the following hypotheses:

**Hypotheses 3 (H3).** *The higher the grain price, the higher the level of fertilizer use.*

**Hypotheses 4 (H4).** *Higher grain sales have a positive effect on the level of fertilizer use.*

The increase in farmers' income may not ideal for relieving overfertilization at this stage in China. Exiting agriculture is an important kind of development pathways of adaptation for many current farmers [38]. Off-farm income are likely to have the greatest impact in decisions relating to the adoption of the soil carbon enhancing practices [17]. However, it is possible that when farmers can make more money by doing other jobs instead of relying on growing grain crops, they may prefer not to apply excessive fertilizer. Thus, off-farm income may have a two-way effect on fertilizer use. Therefore, we adopted the per capita DPI of rural residents as a proxy variable for urban wages and off-farm income. Therefore, this study proposes the following hypothesis:

**Hypotheses 5 (H5).** *Increased per capita DPI of rural residents has a positive effect on the level of fertilizer use.*

### 3.2. Overfertilization Evaluation Model

Frontier production analysis has special advantages compared with other methods of evaluating scientific/technological and production efficiency. It is based on a specific production functional form, and its results are robust and resistant to influence by outliers [31]. In fact, the translog function represents a second-order approximation to any true functional form and places fewer restrictions before estimation than the Cobb–Douglas specification or other more traditional specifications [31]. Following Feng (2008) and Tan et al. (2010) [114,115], we chose the transcendental logarithmic production model to evaluate fertilizer use efficiency:

$$\ln Y_{it} = \beta_0 + \beta_{it} \ln X_{k,it} + \beta_z \ln Z_{it} + \frac{1}{2} \sum_{jk} \beta_{jk} \ln X_{ijt} \ln X_{ikt} + \sum_j \beta_{jz} \ln X_{ijt} \ln Z_{it} + \frac{1}{2} \beta_{zz} (\ln Z_{it})^2 + V_{it} - U_{it} \quad (1)$$

where  $Y_{it}$  is the output of agricultural products per mu,  $Z_{it}$  is the input amount of fertilizer per mu, and  $X_{it}$  is the cost of labor, machinery operation, and other inputs per mu. Other inputs include the costs of seeds, pesticides, irrigation, animal power, and farmyard manure.

When fertilizer use is efficient,  $Z_{it}$  can be replaced with the minimum feasible fertilizer input to produce the optimal model. The utilization efficiency of fertilizers can then be expressed as follows:

$$\ln FE_{it} = \ln \left( \frac{Z_{it0}}{Z_{it}} \right) = \left[ - \left( \beta_z + \sum_j \beta_{jz} \ln X_{ijt} + \beta_{zz} \ln Z_{it} \right) + \sqrt{\left( \beta_z + \sum_j \beta_{jz} \ln X_{ijt} + \beta_{zz} \ln Z_{it} \right)^2 - 2\beta_{zz} U_{it}} \right] / \beta_{zz} \quad (2)$$

where  $FE_{it}$  is chemical fertilizer overuse and  $Z_{it0}$  is the minimum feasible fertilizer input.

### 3.3. The Influencing Factors Model for Overfertilization

Considering that chemical fertilizer use displays the characteristic of “path dependence,” which means that the level of fertilizer applied for a given period is significantly influenced by previous behavior [116], we established a dynamic panel regression model (the Arellano–Bover/Blundell–Bond linear dynamic panel data estimation) with a phase lag of the explanatory variables in order to analyze the causes of fertilizer overuse by farmers. The econometric model was set as follows:

$$FE_{it} = \sum_{j=1}^p \alpha_j FE_{i,it-j} + X_{it} \beta_1 + W_{it} \beta_2 + v_i + \epsilon_{it} \quad (3)$$

where

$\alpha_j$  are  $p$  parameters to be estimated,

$X_{it}$  is a  $1 \times k_1$  vector of strictly exogenous covariates,

$W_{it}$  is a  $1 \times k_2$  vector of predetermined covariates,  $v_i$  is the panel-level effects, and

$\epsilon_{it}$  are independent and identically distributed over the whole sample with variance  $\sigma_\epsilon^2$ .

$X_{it}$  includes quantity sold (Q), sales (Sales), cash cost (Cashcost), and cash earnings (Cashben);  $W_{it}$  includes DPI and grain price (Price).

### 3.4. Data and Data Sources

China has taken measures to gradually allow the price of chemical fertilizers to rise as part of a transition toward marketization; the price has risen sharply since 2004. In 2005, the country began implementing a subsidy program for soil testing and chemical fertilizer use in order to address low fertilizer utilization rates and overfertilization [117–119]. It is noteworthy how farmers' behavior regarding fertilizer use has changed in these contexts. Therefore, this study focused on relevant data from 2004 to 2018. The three grain crops used in the analysis were wheat, rice, and maize. Diverse rice varieties are grown in China, including early indica, indica, late indica, and japonica; we selected japonica for the analysis, as it is the most representative variety. Considering that the crops are differently distributed among the various provinces due to large differences in natural conditions, we focused our research on the corresponding major planting provinces for each grain crop. Table 1 shows the regions associated with the three selected crops.

The input–output data of 2004–2018 for the three crop types were obtained from the National Farm Product Cost/Earning Survey (2003–2019) [120]. Other data were obtained from the China Statistical Yearbook, China Rural Statistical Yearbook [11,121,122]. The aforementioned data sources are all official publications and represent the most authoritative available data.

Other inputs in the production functions include seed costs, pesticide costs, mechanical handling costs, irrigation and drainage costs, and animal power costs. The price of chemical fertilizers here is the mixed average price, which is the cost of fertilizers divided by the consumption of fertilizers per acre.

**Table 1.** Main planting provinces for wheat, maize, and rice (japonica).

Crop	Main Planting Provinces
Wheat	Anhui, Gansu, Hebei, Henan, Heilongjiang, Hubei, Jiangsu, Inner Mongolia, Ningxia, Shandong, Shaanxi, Shanxi, Sichuan, Xinjiang, Yunnan
Maize	Anhui, Gansu, Guangxi, Guizhou, Hebei, Henan, Heilongjiang, Hubei, Jilin, Jiangsu, Liaoning, Inner Mongolia, Ningxia, Shandong, Shanxi, Shaanxi, Sichuan, Xinjiang, Yunnan, Chongqing
Rice (japonica)	Anhui, Hebei, Henan, Heilongjiang, Hubei, Jilin, Jiangsu, Liaoning, Inner Mongolia, Ningxia, Shandong, Yunnan, Zhejiang

#### 4. Results, Analysis, and Discussion

##### 4.1. Evaluation and Analysis of the Degree of Overfertilization

The descriptive statistics of the variables are shown in Table 2.

**Table 2.** Descriptive statistics.

Variable	Mean	Std. Dev.	Min	Max	Observations
Output	918.45	387.423	213.77	2091.11	716
Fertilizer Input	119.285	35.869	12.02	241.96	716
Labor Input	343.707	231.96	27.93	1310.11	717
Mach Input	87.16	55.894	0.05	276.2	712
Other Input	123.405	51.606	0	335.48	644
Q	288.178	126.324	12.8	688.91	717
Sales	601.725	351.75	18.1	1832	717
DPI	7373.397	4135.51	1721.55	27,302.4	717
Price	101.648	27.156	45.47	169.33	717
Cashcost	43.934	16.032	15.23	110.98	717
Cashben	57.743	19.577	−8.43	113.33	717

Where, Output represents the output of agricultural products per mu; Fertilizer Input is the amount of fertilizers per mu, measured in kilograms; Labor Input is the labor cost; Mach Input is the machinery operation cost; and Other Input represents pesticide cost, seed cost, irrigation cost, and animal power cost per mu. The other variables include quantity sold per mu (Q), sales per mu (Sales), per capita disposable income of rural residents (DPI), average selling price per 50 kg of main products (Price), cash cost per mu (cash cost), and cash earnings per mu (Cashben).

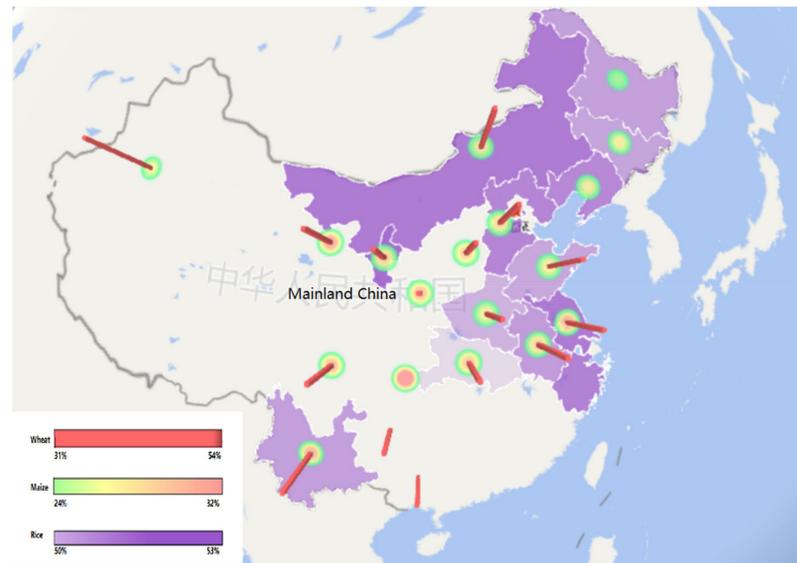
We used the Stata software developed by StataCorp (College Station, TX, USA) to estimate the degree of overfertilization and investigate the influencing factors. In this study, the production frontier function analysis method was used, and a time-invariant model was constructed to deal with the panel-data. The results show that mean degree of overfertilization for wheat, maize, and japonica rice is 51.05%, 30.07%, and 51.39%, respectively (see Table 3). The standard deviations are small, indicating that overfertilization in the production of the three grain crops has been prevalent and stable over the years.

**Table 3.** Degree of overfertilization for wheat, maize, and rice (japonica).

Variable	Mean	Std. Dev.	Min	Max	Observations
Wheat	0.5105465	0.0309461	0.3780085	0.5671189	168
Maize	0.3006699	0.0280272	0.2500580	0.3569950	227
Rice (japonica)	0.5139477	0.0150456	0.4637380	0.5486770	192

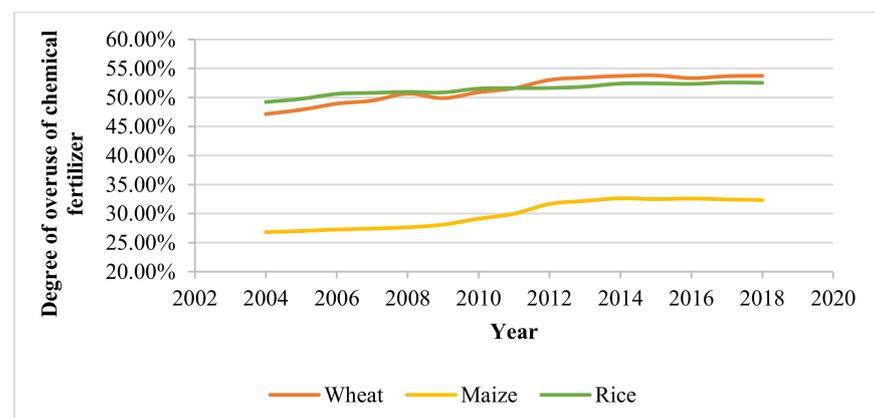
In terms of provinces, the overuse of chemical fertilizer in wheat production was greater in Shaanxi (53.53%) than in other regions; in japonica rice production, overfertiliza-

tion was the greatest in Ningxia (52.99%), followed by Inner Mongolia (52.40%), while in maize production, it was the greatest in Chongqing (35.11%), followed by Gansu (32.34%), as shown in Figure 1.



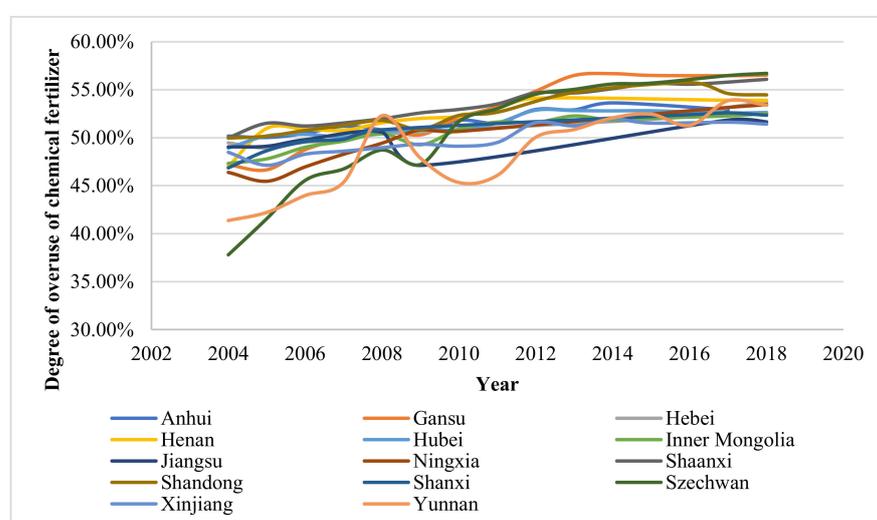
**Figure 1.** Overuse of chemical fertilizer in the production of three grain crops.

Figure 2 shows changes of overfertilization in production of all three grain crops over time. The degree of overfertilization in three kinds of grain production showed an upward trend from 2004 to 2012, whilst the curve was flattened out after 2012. It shows that the overuse of fertilizer in wheat production was more serious than that of japonica rice after 2012, which is completely different from the situation in 2012. The overuse of chemical fertilizers in maize production is relatively low and has shown a downward trend in recent years. Jing (2012) found that the financial crisis of 2007–2009 led to a downward trend in Chinese agricultural prices, which have always been an important factor by which farmers estimate their future income [123]. Therefore, the financial crisis may have had an impact on overfertilization. It is worth noting that the overfertilization in the three types of food production experienced a deceleration in growth in 2007. In wheat production, there were two large increases in the degree of overfertilization (2.43% in 2008 and 2.80% in 2012). A rapid increase in the degree of overfertilization in maize production occurred between 2009 and 2012, while in japonica rice production, there was a steady and slow rate of increase. Maize production reached its maximum degree of overfertilization earlier (2014) than wheat (2015) and japonica rice (2017).



**Figure 2.** Degree of overuse of chemical fertilizer in the production of three crops (2004–2018).

In terms of provinces, only the degree of overfertilization in Gansu, Sichuan, Shaanxi, and Shandong exceeded 55% in wheat cultivation after 2012, as shown in Figure 3. In fact, a key analysis of the changes in overfertilization before and after the financial crisis of 2008 showed that most provinces experienced a slowdown of the rising trend in the degree of overfertilization in 2009. Only the degree of overfertilization of Anhui Province has reduced in 2008, and continued in 2009. Yunnan also experienced a decline in two years (2009 and 2010). It may indicate that farmers in Anhui and Yunnan are more cautious, perceptive, and rational when dealing with special events such as the financial crisis, instead of continuing to increase fertilizer input for the goal of increasing grain yield. Ningxia and Xinjiang only experienced a decline for the first time in 2010, and they seem to have been slightly affected by the financial crisis in 2008. Before 2008, Henan Province, Shaanxi Province and Hubei Province have experienced a decline. Among them, the degree of overfertilization of Henan decreased in two consecutive years (2006–2007), and began to increase since 2008.



**Figure 3.** Estimated degree of chemical fertilizer overuse in wheat production.

In the cultivation of japonica rice, the fluctuation of the degree of overfertilization in Hubei Province was greater than that in other provinces, as shown in Figure 4. Shandong and Inner Mongolia experienced a decline briefly in 2009, and then continued to increase, while Yunnan reached its highest level in 15 years in 2008 and then maintained a low fluctuation rate. Farmers in Yunnan province are more sensitive to economic events and make more accurate decisions when producing wheat and japonica rice. According to the characteristics of overfertilization in maize production in Yunnan Province (see Figure 5), we found that overfertilization not only has regional characteristics, but is also closely related to grain types. The amount of fertilizer used may be related to the importance farmers attach to different grain crops, which can be reflected in the cash income, price and sold amount of grain, etc., which provides evidence for further research on the financial factors of overfertilization.

Overfertilization in maize production showed an upward trend from 25% to 36%, as shown in Figure 5. The upward trend in most provinces stopped in 2008, which may have been due to the financial crisis. In the four years after 2009, most provinces continued to increase fertilizer input. By 2013, the overfertilization levels of almost all provinces began to stabilize. Furthermore, in 84.2% of the provinces, levels have declined slowly since 2016.

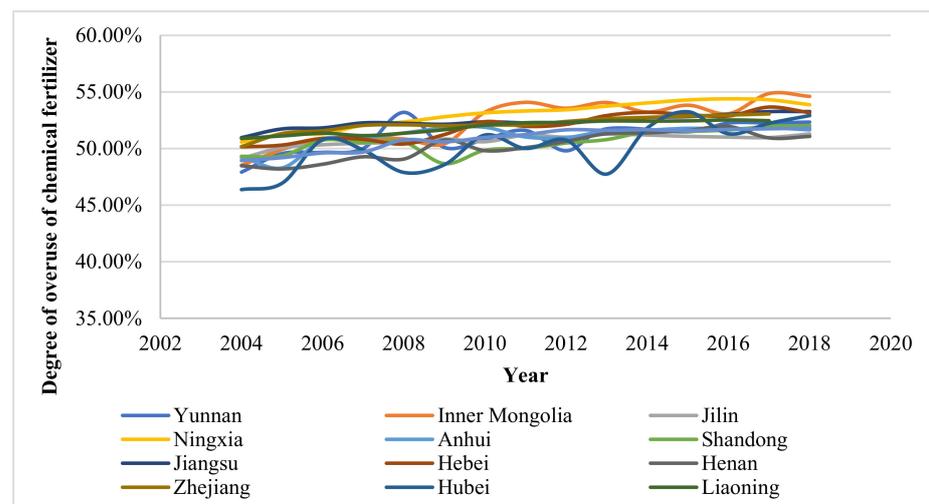


Figure 4. Estimated degree of chemical fertilizer overuse in japonica rice production.

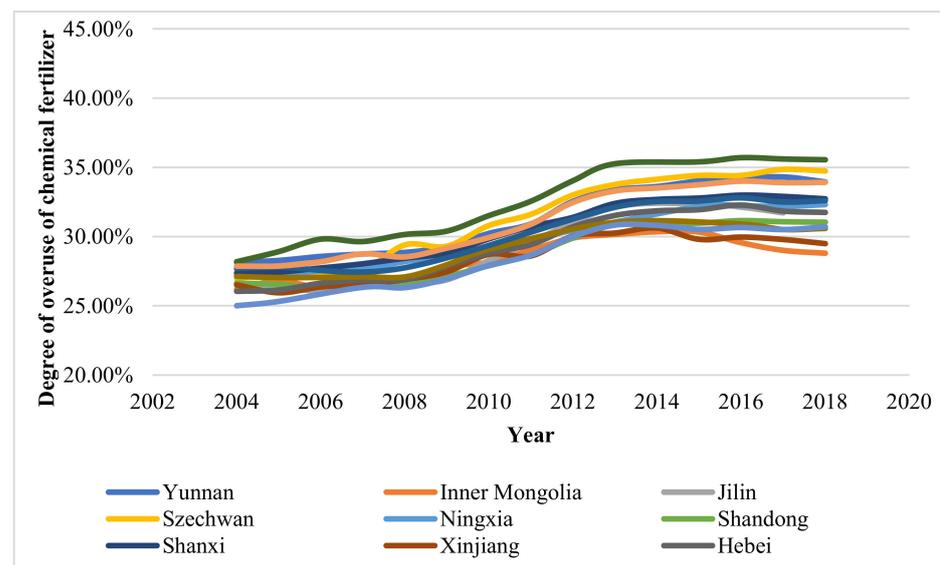


Figure 5. Estimated degree of chemical fertilizer overuse in maize production.

The degree of overfertilization in wheat and maize production varied depending on the region. Overall, overfertilization in wheat production was the most excessive in the Huang-Huai-Hai region, and overfertilization in maize production was the greatest in Southwest China (see Table 4). However, overfertilization in japonica rice production was more severe in the Northern Plateau than in Southwest China. Indeed, in wheat and japonica rice production, the southwest region had the lowest degree of overfertilization, which is completely opposite to what was observed for maize production. The southwest is one of the main maize-producing areas in China, and it is easier to increase production there than in the Northern Plateau and Huang-Huai-Hai Plain, which are high-risk areas for natural disasters [124]. Thus, farmers in Southwest China have high expectations for chemical fertilizers. Compared with other regions, the economy of the Yangtze River region is relatively developed, with more jobs and high per capita income, which may give farmers a better sense of the rate of return. This may explain why the degree of overfertilization in the Yangtze River region was moderate for all three crops.

**Table 4.** Degree of overfertilization in the production of three major grain crops in various regions of China.

	Wheat	Maize	Rice (Japonica)
Northeast China (Heilongjiang, Jilin, Liaoning)	–	28.17%	51.14%
Huang-Huai-Hai region (Shandong, Henan, Hebei)	51.83%	28.90%	50.92%
Yangtze River region (Jiangsu, Anhui, Hubei, Zhejiang)	51.15%	30.52%	51.42%
Northern Plateau (Shanxi, Shaanxi, Inner Mongolia, Ningxia)	51.32%	29.89%	52.70%
Southwest China (Sichuan, Chongqing, Yunnan, Guizhou)	49.48%	32.34%	50.91%
Northwest China (Gansu, Xinjiang)	51.26%	30.33%	–

#### 4.2. Effects of Financial Factors on Overfertilization

As the explanatory variables in Equation (3) contain the lag value of the explained variable, it is a typical dynamic panel model. To obtain consistent estimations of the coefficient for each explanatory variable, this study adopted the Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation.

The maximum lag periods of the dependent variable (FE) for wheat, maize, and japonica rice were five, six, and three, respectively. The DPI and grain price (Price) were used as predetermined variables. Quantity sold (Q), sales (Sales), cash cost (Cashcost), and cash earnings (Cashben) were regarded as endogenous variables for the purposes of the model. Taking the modeling process for wheat production as an example, the current term and lag terms (first-order to fifth-order) of DPI and grain price (Price) were used as predetermined variables. The current terms and lag terms (first-order to fifth-order) of Q, Sales, Cashcost, and Cashben were regarded as endogenous variables. The instrumental variables for modeling of fertilizer overuse in wheat production are listed in Table 5.

**Table 5.** Instrumental variables for modeling of chemical fertilizer overuse in wheat production.

Type of Equation	Generalized Method of Moments (GMM)-Type	Standard
Difference equation	L(2/.)FE L(1/.)L5.DPI L(1/.)L5.Price L(2/.)L5.Q/Sales/Cashcost	D.Q D. Sales D. DPI D. Price D.Cashben
Level equation	LD.FE L5D.DPI L5D.Price L6D. Q/Sales/Cashcost	_cons

The Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation results are presented in Table 6. The second-order autocorrelation tests (AR(2)) and the Sargan test both gave results greater than 0.05, indicating that the instrumental variables in the model were effective. As can be seen from the estimation results, the higher the degree of overfertilization in the previous year, the more serious the overfertilization in the next year; this applied to the production of all three crops, although overfertilization in maize production had the strongest path dependence.

Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation demonstrated that the degree of overfertilization in the production of wheat, maize, and japonica rice was affected by cash earnings, grain price, DPI, and cash costs in previous years. This shows that there are common factors affecting fertilizer use in the production of all three grains. Overfertilization in wheat and maize production was also related to quantity sold and sales. Cash earnings had a positive impact on the degree of overfertilization in the production of wheat and maize, which validated H1. The higher the cash cost, the lower the degree of overfertilization; therefore, H2 was verified. The higher the grain price of maize, the greater the degree of overfertilization, which verified H3. The sales of maize significantly affected the degree of overfertilization; the greater the sales, the greater the degree of overfertilization. Therefore, H4 was verified. In addition, the higher the DPI, the greater the degree of overfertilization; hence, H5 was verified.

**Table 6.** Coefficients of the factors influencing overfertilization.

Variable	Wheat	Maize	Rice (Japonica)
L.1	0.188 ** (2.41)	0.78 *** (6.1)	0.389 *** (3.62)
L.3	–	–	0.29 *** (7.5)
L.4	0.57 *** (6.61)	0.319 * (1.91)	–
L.5	–	–0.635 *** (–2.95)	–
L.6	–	0.342 ** (1.96)	–
Cashben	–	–	–0.001 *** (–2.77)
L.1	–	0.000 *** (–3.69)	–
L.2	0.001 *** (3.12)	0.001 *** (2.89)	–
L.3	–	–0.001 *** (–4.15)	–
Price	–	–	0.0005 * (1.73)
L.1	–	0.001 *** (3.44)	–
L.2	–	0.000 *** (–3.63)	–
L.3	–0.001 ** (–2.44)	–	–
L.4	–	–0.001 *** (–6.05)	–
L.5	–	0.001 *** (6.07)	–
DPI	0.00001 *** (2.71)	0.000 *** (–2.91)	–
L.1	–	0.000 *** (3.41)	0.000 * (–1.6)
L.2	0.005 * (2.39)	0.000 *** (–2.99)	0.000 * (1.8)
L.4	–0.004 *** (–3.19)	–0.001 *** (–6.05)	–
L.5	–	0.001 *** (6.07)	–
Cashcost	–	–	–
L.1	–0.001 *** (–3.12)	–	–0.0005 *** (–2.66)
L.3	–	–0.001 *** (–2.95)	–
L.4	0.001 *** (5.45)	0.002 ** (2.66)	–
L.5	0.001 *** (5.71)	0.001 *** (–5.97)	–
Q	–	0.000 *** (1.68)	–
L.1	–	0.000 * (2.64)	–
L.3	–0.0003 * (–3.33)	–	–
L.5	–	0.000 * (1.95)	–
Sales	–	0.000 *** (3.36)	–
L.1	0.0001 ** (2.16)	0.000 *** (–2.57)	–
L.2	–0.0001 ** (–2.08)	–	–
L.3	0.0001 *** (2.63)	–	–
L.4	–0.0001 ** (–2.25)	–	–
L.5	–	0.000 ** (–2.02)	–
L.6	–0.003 * (–2.25)	0.000 * (1.8)	–
C	0.126 ** (2.27)	–0.069 * (1.68)	0.167 *** (3.14)
Obs	70	87	147
Mean dependent	0.523	0.314	0.518
SD dependent	0.024	0.019	0.013
AR(1)	[0.0106]	[0.0114]	[0.0177]
AR(2)	[0.2244]	[0.5948]	[0.1768]
Sargan test	[0.9999]	[1.0000]	[0.8819]

Note: The values in parentheses are the *t*-statistic regression coefficients. The values in square brackets are the probability (*p*) values of the appropriate corresponding test statistics. \* 5% significance level; \*\* 1% significance level; \*\*\* 0.1% significance level.

## 5. Conclusions

First, this study adopted the translog function estimation method to evaluate the degree of overfertilization for wheat, rice (japonica), and maize in 21 provinces of China based on panel-data from 2004 to 2018. The results showed an upward trend in the degree of overfertilization for all three grain crops from 2004 to 2018. However, the degree declined in 2007 and 2008, which may indicate that the financial crisis of those years had a short-term

impact on overfertilization. In addition, the degree of overfertilization in the production of the three grain crops varied across regions; overfertilization in wheat and japonica rice production was the lowest in Southwest China, which was completely opposite to the case for maize production (highest in Southwest China).

Further, this study used the dynamic panel-data regression estimation method to explore the impact of financial factors (cash earnings, grain prices, cash costs, DPI, and grain sales) on overfertilization from the perspective of farmers' economic rationality. In particular, it explored the important role of cash-related input factors (cash earnings and cash costs) in farmers' fertilization decision-making. The results showed that cash earnings from wheat and maize had a positive effect on the overuse of chemical fertilizers, whereas the opposite was true for japonica rice. The higher the price of maize, the greater the overuse of chemical fertilizers; in fact, the past price of maize was a good predictor of the overuse of chemical fertilizers. Cash costs and DPI had opposite effects on overfertilization in the production of the three grain crops. On the one hand, the higher the cash cost, the lower the degree of overfertilization. When cash cost is high, cash may be spent not on fertilizer input, but on other inputs such as farm machinery. Another possibility is that a higher cash cost in previous years influences farmers' future cost planning, that is, reducing inputs such as of chemical fertilizers. On the other hand, the higher the DPI, the greater the degree of overfertilization. As a source of funds for production input, the year-on-year increase in rural disposable income has made overfertilization more serious. In addition, maize sales (the returns of the money invested in maize production) had a stable long-term positive effect on chemical fertilizer input.

The main contributions of this study are as follows. First, the study systematically analyzed and compared the degree of overfertilization in the production of three major grain crops in China over a period of 15 years at regional and national level. It makes up for the one-sided presentation of overfertilization in a certain kind of grain crops or a certain area in previous studies, and shows the situation of fertilizer used in the production of different kinds of grain crops in detail, which is of great importance for the follow-up proposal of targeted strategies for overfertilization in different grain crops production. Second, this study found and analyzed the changes of overfertilization before and after the financial crisis, which provides evidence for the impact of major economic events on overfertilization. Third, this study found that cash earnings, cash cost, and grain sales are important factors affecting farmers' fertilization decision, which confirmed farmers' economic rationality and the inclination to neglect the time value of money in agricultural production, such as that of fertilizer input costs. In addition, improving agricultural product market information disclosure may affect farmers' fertilization decision-making. The findings will help to promote the formulation of support policies such as exploratory design of payment methods by the state and the financial service sector, so as to help to reduce fertilizer use. According to the results of this study, strengthening the interaction between government regulation, market construction, and farmers' decision on chemical fertilizer will effectively reduce the use of chemical fertilizer in agriculture practices, which is an expansion of the scientific studies and successful experience of the EU and the US in reducing chemical fertilizer use.

Nevertheless, there are still limitations to this study. First, this study derived figures for overfertilization in Chinese grain production only through theoretical estimation. If this method can be combined with field experiments, it may demonstrate the dual role of financial factors and soil absorption on overfertilization. Second, although the effects of cash flow factors on overfertilization were explored, the components of cash cost were not further subdivided. Moreover, the time value of money considered may not fully show the return on investment in grain production.

Therefore, future researchers should analyze the impact of the cash used to purchase fertilizer and the limiting or encouraging effects of other inputs, cash earnings, and cash costs that are combined with the interest rate to more accurately reflect farmers' financial considerations of fertilization decision. Moreover, further studies on how to use and

improve the inhibiting effect of cash cost on overfertilization will have implications for optimization of financial services by the financial institutions. Additionally, validation of farmers' decision on chemical fertilizer through Questionnaire Survey Design is a new research direction, which will help to find out what farmers are thinking about when making fertilization decisions. In addition, studies on whether farmers' reactions to economic events such as the 2007–2009 financial crisis can predict similar reactions to government policies for controlling fertilizer application could help accelerate the development and implementation of relevant policies, for instance with regard to reducing fertilizer use in specific regions.

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