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Factors affecting farmers' decisions on fertilizer use: A case study for the Chaobai watershed in Northern China

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Abstract

The Chaobai watershed in northern China is the most important source of drinking water for Beijing. The level of fertilizer use, especially overuse, as well as farming practices in the region have a great impact on the water quality downstream and affect an enormous number of people. This study analyzes the factors influencing the farmers' decisions on fertilizer use and the implications for water quality. The analysis is based on a survey of 349 farm households. It takes into consideration both farm and farmer specific characteristics and farmers' subjective evaluations of factors shaping their decisions. Regression models are used to examine the determinants of fertilizer use intensity across farm households and to investigate the factors influencing the overuse of nitrogen. The results suggest that many of these subjective factors have great significance in determining famers' decisions. The results also show that irrigation, gains in crop yield and higher earning goals are positively correlated with fertilizer use intensity, while farm size, manure application, soil fertility and the distance to fertilizer markets are negatively correlated. Investigation of the overuse problem shows that higher education level significantly reduces the probability of over-fertilization. Based on these findings a few policy relevant implications are discussed.

Keywords: China; fertilizer use; subjective evaluation; maize; nitrogen.

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1. Introduction

Fertilizer is regarded as crucial for crop production by small-scale Chinese farmers. Intensive use of chemical fertilizer (henceforth, fertilizer) in conjunction with improved seed varieties and expanded irrigation have brought about rapid growth in China's grain production. From 1983 to 2005, average fertilizer use increased from 169 kg/ha to 390 kg/ha,[i] of which about two-thirds were nitrogen-based. In the same period, the grain yields grew from 3.7 tons to 5.3 tons per hectare. Zhu and Chen[ii] suggest that there is a strong positive correlation between annual food production and annual consumption of fertilizers during the period of 1949-1998. However, increased fertilizer use has not come without costs to society. Empirical studies have shown that on many high-yielding farmlands, the nitrogen fertilizer application rate has been too high, resulting not only in decreased efficiency and large costs, but also negative impacts on air and water quality.[iii] In addition, eutrophication has become a serious environmental concern in many freshwater bodies in China. For example, Sun and Zhang[iv] reported that 61% of the 28 lakes investigated were significantly eutrophied. A recent algae bloom in the Tai Lake has threatened the water supply of over two million people in Jiangsu Province.[v] Among all the causes of the eutrophication and degradation of water quality, nutrient loss from agricultural land has been an important one.[vi]

The Chaobai watershed, located in the upstream Miyun reservoir, is Beijing's most important source of drinking water and provides about 70% of Beijing's surface water supply.[vii] With the point source pollution from industries in the watershed being under stringent control, non-point sources, mainly from agricultural activities, have become the primary polluters of the reservoir's water. The Wang et al.[viii] study shows that non-point source pollution contributes to 73% of COD (chemical oxygen demand), 94% of NH3-N, 75% of total N and 94% of HPO4 in the Miyun reservoir's total load. How best to influence farmers' fertilizer use to reduce water pollution without compromising their welfare and development opportunities is an important question to be investigated. The motivation of the current study is to understand the factors determining farmers' fertilizer use for formulating effective intervention strategies.

In the existing literature, the analysis of the decisions on fertilizer use has mainly considered the factors lying within the public domain (e.g. prices and marketing, fertilizer provision and distribution, research and credit, etc.), and on agro-climatic conditions and characteristics of the farm or the farmer (e.g. education, age, experience and farm resources).[ix] Most earlier works on fertilizer use by economists focus on fertilizer adoption and assume that farmers make adoption decisions based on utility maximization. However, social scientists, especially anthropologists and sociologists, have argued that farmers' subjective assessments of agricultural technologies are also important in influencing their adoption behaviour.[x] For example, the works of Adesina and Zinnah, Adesina and Baidu-forson and Sall et al.[xi] show that farmers' perceptions have been found important in adoption of modern crop varieties in several regions in Africa.

Given that a majority of Chinese farmers use fertilizer and adoption is not a problem, this paper intends to investigate the factors determining the intensity of fertilizer application and its overuse. Building on earlier works concerning farmers' decision making and behavioural decision theory[xii] and drawing on our household survey, this study investigates the effects of both conventional farm and farmer related characteristics as well as farmers' subjective evaluations on fertilizer use. The case study of the Chaobai watershed in China is used to provide insights into the most important determinants of fertilizer use.

2. Data and description of farming characteristics

2.1 The household survey

Data used in the analysis were collected from a survey of farm households in the Chaobai watershed from July to November 2006 in collaboration with the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. The study area consists of three counties of Hebei province, namely Chicheng, Fengning and Luanping, covering an area of 10,877 km2 (Fig. 1). We first selected townships in each county to ensure a wide coverage of the geographical zones, followed by the selection of three representative villages in each township. Around ten households in each village were chosen randomly to conduct face-to-face interviews with the head of each household or the ones responsible for farming activities. In total, the survey covered 34 villages and 349 farm households. These represent about 5% and 0.3% of the total number of villages and farm households in the study area, respectively.

The questionnaire of the survey was designed to solicit information on farmers' water use and fertilizer use behaviours in farming activities. It encompasses households' demographics, farmland and crops, farming inputs and outputs including manure and fertilizer use, farmers' ownership of assets and income sources. In particular, the survey contains a series of questions relating to farmers' subjective assessment of the factors influencing their decisions about fertilizer use. Farmers were asked to list the most influential factors when deciding how much fertilizer to use. In addition, farmers were asked to rate the decision variables according to their importance.

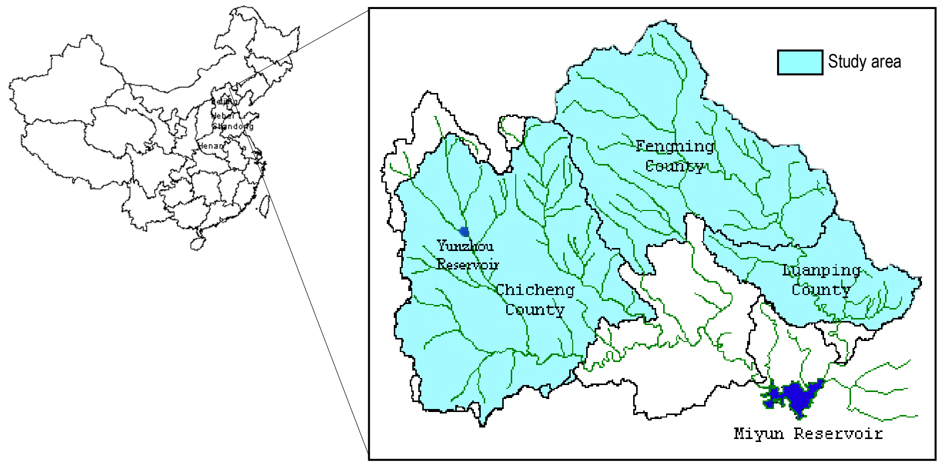

Figure 1: Location of the study area in the Chaobai watershed

2.2 Farming characteristics

The three counties in the study area are all classified as national poor counties, with agriculture as the main economic sector. The general figures relating to social, economic and natural conditions of the study area and surveyed farmers are shown in Table 1. Maize, the major crop, is grown once a year. Other crops include millet, sorghum, beans and tubers. On a small percentage of land, paddy rice and cash crops such as oil seeds and vegetables are grown. Due to the semi-arid climate and the mountainous environment, most crops are rainfed, and irrigated land accounts for less than 20% of the arable land. Fallow or routine rotations of crops are rarely practiced in the region. Nutrient replenishment relies almost solely on the application of manure and chemical fertilizer.

Fertilizer has been used in significant amounts in this region and tends to increase over time (Fig. 2). The higher prices of fertilizer and maize on the national level before 1996 resulted from the escalating demand for fertilizer induced by the increase in government purchases of agricultural products. Since 1996, under certain government regulations,[xiii] the prices of both fertilizer and maize have remained relatively stable. The ratio of the price indices of fertilizer to maize has varied slightly in that time, between 0.90 and 1.16.

In our survey area, the main fertilizer used at seeding is diammonium phosphate (DAP), and the main topdressing fertilizer is nitrogen, including predominant use of urea and ammonium bicarbonate. Potassium fertilizer application has been largely ignored on grain crops. Table 2 lists the average level of fertilizer intensity for a few selected crops based on our survey data. Here ammonium bicarbonate is converted to equivalent urea based on the nitrogen content and is added to the amount of urea applied.

Characteristics	Chicheng county	Fengning county	Luanping county
Area (km²)	5287	4174	1416
Arable land (ha)	47,440	30,167	9,973
Water resources (million m³)	349	295	156
Population (persons)	280,777	223,600	118,182
Agricultural output value (million yuan)	851	778	537
Number of surveyed farm households	167	122	60
Age of household head (years)	48.4	47.5	48.8
Education of household head (years)	4.95	6.01	6.08
Household size	3.2	3.5	3.2
Cultivated area per household (ha)	0.58	0.63	0.41
Irrigated area per household (ha)	0.17	0.17	0.17
Land growing maize per household (ha)	0.30	0.31	0.26
Total number of plots	7.8	7.9	5.2
Total fertilizer use (kg/ha)	528	592	682
Maize yield (kg/ha)	6255	6698	7718
Farm income (yuan/person)	790	682	623
Total income (yuan/person)	2357	3187	3460

Table 1: General characteristics of the study area and surveyed farmers by county. (Source: Authors' survey and the Statistical Yearbooks of Chicheng, Fengning and Luanping counties, 2005.)

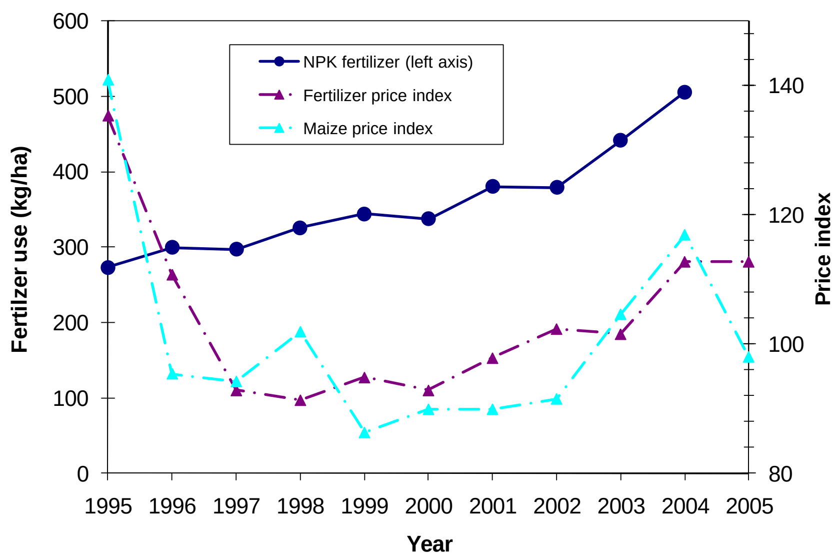

Figure 2: NPK fertilizer use per hectare of gross sown area (kg/ha) and fertilizer and maize price indices, 1995-2005. (Source: Statistical Yearbooks of Chicheng, Fengning and Luanping counties, 1995-2004, China Agricultural Development Bulletin, 2005.)

Crops	Diammonium phosphate	Urea	Fertilizer cost	% of total capital inputs	Crop yield
	kg/ha	kg/ha	yuan/ha	%	kg/ha
Maize	178	402	1311	53	6360
Coarse grains	89	207	642	45	3660
Rice	159	530	1392	46	7185

Table 2: Average fertilizer use on selected crops in the study area. (Source: Authors' survey.)

In maize plots, DAP is on average applied on 178 kg/ha, in conjunction with 402 kg/ha for urea. Compared with maize, less fertilizer is used on coarse grains but more is applied to paddy rice. Farmers tend to emphasize the use of nitrogen fertilizer but undervalue the effects of phosphorous and potassium fertilizers. The actual rate of N and P2O5 application of 1:0.38 diverges significantly from the recommended ratio of 1:0.6-0.7[xiv] for this region. The situation may be partly attributed to the farmers' experiences with fertilizer, which started with nitrogen (i.e. urea), and were gradually exposed to phosphate fertilizer. The knowledge of potassium came last and remains mostly lacking. The fertilizer cost for maize accounts for 53% of total capital inputs, which is the highest among grain crops planted in the region. This implies that farmers put an emphasis on fertilizer application in maize to secure high yields. As maize is the dominant crop of the farming system, the subsequent analysis of decisions on fertilizer use will focus on maize only.

3. Conceptual framework

Following the literature on fertilizer use and farmers' decision making, fertilizer use intensity can be analyzed as a function of farm and farmer related variables, agro-climate conditions and variables related to farmers' subjective assessments. The dependent variable is the total amount of fertilizer per hectare including DAP and all nitrogen based fertilizer. For the sake of comparison, we converted all other types of nitrogen fertilizer to urea-equivalent amounts based on their nitrogen contents. The empirical model is specified as:

$$Y_i = \alpha + \beta X_h + \delta X_c + \gamma X_{sub} + \varepsilon_i \qquad (1)$$

where Yi denotes the total fertilizer per hectare (kg/ha) on maize land for the ith household, Xh is a matrix of farm and farmer characteristics, Xc stands for agro-climate conditions, Xsub refers to the variables related to farmers' subjective evaluations and ε is the usual error term. α, β, δ and γ are the parameters to be estimated. The measurement data representing climate conditions, such as precipitation and temperature, are similar across the surveyed area and thus too coarse to be used in this model. The agronomic conditions can be in part captured by including two regional dummies, Fengning and Luanping counties. Chicheng county was chosen as the benchmark because it occupies the largest portion of the study area and provides the most important source of water. The selection of the independent variables of Xh and Xsub will be described in detail in the following section. As all the farmers surveyed use fertilizer, we apply an ordinary least square

(OLS) estimation instead of Tobit to the models explaining the variation in fertilizer use intensity.

Furthermore, due to the serious problem of overuse of nitrogen fertilizer as demonstrated by the survey data, we estimate a probit model to identify the specific factors affecting over-fertilization. Farmers are split into two groups according to the cut-off value of 450 kg/ha of urea application, below which farmers are regarded as normal users and above as overusers. The cut-off value is about the upper limit of the recommended nitrogen level for this region.[xv] The probit model can be described as follows. The dependent variable (Y) takes binary values; 1 if the farmer overuses fertilizer, and 0 otherwise. Following Wooldridge,[xvi] the model can be specified as:

$$\begin{aligned} Prob(Y=1) &= F(\beta' X) \\ Prob(Y=0) &= 1 - F(\beta' X) \end{aligned} \qquad (2)$$

where F is a function taking on values strictly between zero and one. β is a set of parameters to be estimated, and X refers to the vector of explanatory variables. The probit model assumes F is the cumulative distribution function of normal distribution, and the model can be derived from an underlying latent variable model. Let Y* be an unobserved, or latent, variable, determined by

$$Y^* = \beta' X + \varepsilon \qquad (3)$$

where $\varepsilon \sim N(0,1)$ and εi and εj $(i \neq j)$ are independent. The observable binary variable Y follows:

$$\begin{aligned} Y &= 1 \ \ if \ Y^* > 0 \\ Y &= 0 \ \ if \ Y^* \leq 0 \end{aligned} \qquad (4)$$

The primary goal of a probit model is to explain the effects of X on the response probability. The parameters β are estimated by maximum likelihood using STATA 9. A similar approach has been applied in previous studies of adoption of fertilizer or modern crop varieties.[xvii]

The following set of variables is considered in this study: 1) personal attributes of the farmer: age, level of education, family subsistence pressure; 2) farming system and resource characteristics: cultivated area, manure availability, access to irrigation, soil fertility rated by the farmer, share of hilly land, and the liquidity position of the farmer; and 3) access to fertilizer: distance to fertilizer market. The variables used in this analysis are defined in Table 3.

Variables	Variable description	Mean	Standard deviation
Dependent variables			
Fertilizer use	Total fertilizer used per hectare (kg/ha)	577	201
Phosphate	Diammonium phosphate (DAP) per hectare (kg/ha)	177	87
Nitrogen	Urea equivalent per hectare (kg/ha)	400	173
Personal attributes			
Age	Age of household head (years)	48	10
Education	Education of household head (years)	5.5	2.6
Dependent ratios	Number of dependents/household size	0.19	0.19
Resource characteristics			
Farm size	Total cultivated land (ha)	0.55	0.29
Manure	Manure applied (ton/ha)	11.1	20
Irrigation	Proportion of irrigated land in maize land	0.46	0.45
Soil fertility	Soil fertility of maize plots (1=unfertile 2=average 3=fertile)	1.75	0.66
Off-farm job	Percentage of off-farm income in total household income	0.49	0.32
Agricultural assets	The value of household agricultural assets (yuan)	3416	4838
Hilly area	Share of hilly land in total land area	0.24	0.23
Other variables			
Expected yield gain	The gain in yield from fertilization (kg/ha)	2000	517
Distance	Distance from fertilizer market (township) (km)	3.39	2.76
Urea price	The price of urea (yuan/kg)	2	0.11

Table 3: Definitions and descriptive statistics of variables used.

Education gives farmers better access to information about the fertilizers and more knowledge of how much fertilizer to use. Thus education is expected to favorably affect fertilizer decisions. On the other hand, in a situation when nitrogen fertilizer is overused, better knowledge of fertilizer has the effect of neutralizing the tendency of overuse. Likewise, the effect of age is not straightforward in the adoption literature.[xviii] It could be that older farmers have more experience in farming and have better access to the technologies than younger farmers. On the other hand, older farmers are more risk averse and prudent than younger farmers and have a higher likelihood of applying greater amounts of fertilizer. The more dependents in a family, the greater the pressure to provide subsistence crops. The dependent ratios are included to capture such effects. It is hypothesized that the more intense the subsistence pressure, the greater will be fertilizer use intensity.

The effect of farm size on farmers' adoption behavior has been mixed in the literature. Farm size is found to be negatively correlated with fertilizer intensity in Coady,[xix] positively correlated in Waithaka et al.,[xx] and insignificant in Freeman and Omiti[xxi] as well as Chianu and Tsujii.[xxii] With regard to manure, about 40% of the households surveyed apply it. Manure usually comes from animal excreta and the possession of livestock by a household usually implies its availability. Due to absence of a market for manure, it is not correlated with farmers' economic status and thus exogenous in the model. It is hypothesized that manure application influences fertilizer use negatively as manure replenishes nutrients to soil. Irrigation plays an important role in determining fertilizer use. Where water is not available at the right times for crop growth, fertilizer will have no or even adverse effects. Irrigation is thus hypothesized to positively contribute to fertilizer levels. With respect to soil fertility, relatively fertile land requires less fertilizer and thus is expected to negatively affect fertilizer use. The share of hilly lands as a percentage of total cultivated land is expected to be negatively correlated to fertilizer application intensity. The distance of villages to the township seat is included to capture the access to the fertilizer market. As the distance increases, the fertilizer use is expected to decrease.

The financial liquidity constraint is often cited as an important determinant of fertilizer use.[xxiii] Here two variables are used as proxies for the availability of liquidity to the household. The first are household assets, measured as the values of agricultural machinery, tools and vehicles as well as draft animals. This is expected to exercise a positive influence on fertilizer use. Secondly, when farmers engage in off-farm work, it usually implies that the household has a diverse source of income, an indication of cash available to the household for input purchases. The off-farm variable is expected to have a positive effect on fertilizer use. As the rural credit market is not well developed in this region, in times of difficulty farmers usually use their social networks or informal ways to attain money for fertilizer. Credit is thus not included as a variable.

We did not include the ratio of fertilizer price to crop price as an explanatory variable because the ratios obtained from our samples are not sufficiently varied. Due to government support in China, maize prices remain at around 1 yuan/kg in the region and fertilizer prices do not exhibit sufficient variation either. This leads to an almost uniform ratio of relative prices, which could not be used to capture the real effect on fertilizer consumption.

Some of the above variables such as farm size, irrigation status and soil fertility may raise the concern of endogeneity. However, in China's context, where land is relatively equally allocated over the rural population, the farm size is not much influenced by farmers' capabilities. Leasing land happens on a small scale in the region. Therefore farm size can be regarded as exogenous in our models. Relating to land allocation, irrigation status and soil fertility of the farmland are also largely out of a farmer's control. By and large, both canal irrigation systems and well irrigation in the region are financed by the government and farmers have little control over the irrigation status of their lands. Although private tubewells are on the rise in North China,[xxiv] our study area is falling behind in such investments. Therefore, irrigation and soil fertility can be regarded as exogenous as well.

4. Description of factors relating to farmers' subjective evaluation on fertilizer

Factors	Position (% respondents)							
	1	2	3	4	5	6	7	Total (%)
Growth and/or density of seedlings	36	18	4	2				60
Own experience	31	24	10	1	0.9			67
Yield gain from fertilization	10	11	8	2	0.6	0.9	0.6	33
Soil fertility	9	8	4					21
Types of crop planted	5	4	3	1				13
Weather, rainfall	3	5	3					11
Manure availability		6	2					8
Knowledge of fertilizer		2	1	1				4
Cost of fertilizer			3					3
Capital availability				1		0.6		1.6

Table 4: Factors influencing fertilizer use decision making. (Source: Authors' survey.)

The factors that play a role in farmers' decisions on fertilizer use were elicited in our household survey. The first question posed was 'what factors do you consider first, second, third, etc. when deciding on how much fertilizer to apply?' In the survey, farmers were encouraged to freely express thoughts related to their fertilizer use. The responses were given in sequence and can be put into ten categories as shown in the first column of Table 4. Positions one to seven correspond to the degree of priority given to the various factors on a scale of one to seven. A maximum of seven factors were provided by the farmers, who collectively generated the total of ten listed below. The values in Table 4 are the percentage of respondents in each position for each of the ten categories. Although the survey techniques proved valuable in this particular case, if not well-designed and administered, this method can lead to potential bias in survey results. This is especially the case when farmers are unable to explicitly describe the factors or put them in a sequence and consequently additional indications or guidance have to be provided to facilitate the process. It is therefore important to pre-test the questionnaire with the various segments of farmers in the study area to get a grip on their capabilities and willingness to participate in the actual survey.

Among the respondents, 67% of the farmers listed their own experience as an important factor, followed by 60% who listed the growth and/or density of crop seedlings. The yield gain from fertilization and soil fertility are recognized as being important by 33% and 21% of farmers, respectively. Other factors in the list include type of crops planted, weather and rainfall, manure availability and knowledge of fertilizer, etc. It is worth noting that both the cost of fertilizer and capital availability are not frequently considered in the fertilizer use decision. The sequence of the factors listed may reflect the thinking patterns of farmers. In general, more important factors to a farmer are identified relatively early in the sequence. For example, we find that the first few factors identified in position 1 are growth and/or density of crop seedlings (36%), personal experience (31%), yield gain from fertilization (10%),

Decision variables	% respondents					Mean[b]
	Scale of importance[a]					
	1	2	3	4	5	
Own experience with fertilizer (N[c]=345)	0.3	2.6	2.0	7.5	87.5	4.79
Gain in crop yield (N=345)	0.9	5.8	3.2	10.7	79.4	4.62
Effectiveness of fertilizer (N=344)	3.8	7.6	13.4	15.7	59.6	4.20
Soil fertility of your land (N=344)	19.2	21.2	3.8	23.8	32.0	3.28
Amount of manure availability (N=328)	30.2	22.0	4.3	25.0	18.6	2.80
Cost of fertilizer (N=345)	55.1	20.9	2.9	10.7	10.4	2.00
Capital availability (N=345)	62.6	13.3	2.9	11.6	9.6	1.92
Expected work involved in applying fertilizer (N=345)	90.1	7.8	0.6	1.2	0.3	1.14
Neighbors' influence (N=345)	77.2	12.1	1.7	6.9	2.0	1.45
Institutional influence (N=69)	39.1	30.4	7.2	17.4	5.8	2.20
Goals of farming						
Food provision (N=345)	2.3	5.8	0.3	6.1	85.5	4.67
Earnings (N=345)	15.9	16.2	4.1	17.4	46.4	3.62

Table 5: Ratings for importance of decision variables in terms of fertilizer use. (Source: Authors' survey.)
[a]1=not important at all; 2=not important; 3=neutral; 4=somewhat important; 5=very important
[b]Mean of importance scores of all respondents
[c]Number of respondents

soil fertility (9%), type of crops planted and weather. Manure availability and knowledge of fertilizer are considered only from position 2 onwards, while factors such as cost and capital are considered rather late in the fertilizer use decision.

Farmers were asked to rate the level of the importance of a series of decision variables using the Likert scale.[xxv] The variables were predefined before the interviews such that they do not entirely correspond to the factors identified by the farmers in Table 4. The question was 'how important do you think the variable (e.g. own experience) is for your decision on how much fertilizer to apply?' For the goals of farming, the question 'how important is it for you to get food for your household (or earn as much money as possible) from your own farming activities?' was posed. Table 5 shows the percentage of respondents corresponding to the scale of importance for each decision variable.

The majority of farmers regarded their own experience with fertilizer and the gain in yield as important for their decisions on fertilizer use. Although it is not explicitly identified by the farmers as shown in Table 4, the effectiveness of fertilizer was important for about 75% of the farmers. The effectiveness of fertilizer can be influenced by method of placement and frequency of application. It affects the growth of crop seedlings along with weather, irrigation and farm management factors. The views on the importance of manure availability and soil fertility were rather balanced: 44% regarded manure as important and 56% considered soil fertility important. In contrast, the cost of fertilizer was not indicated as important for the majority of farmers. This was often followed by an explanation from farmers that they would apply appropriate amounts of fertilizer no matter what the price because of the vital role fertilizer plays in securing crop yield. Similarly, the majority of farmers did not think that the amount of capital available was important for their decisions on fertilizer use. Most of the above findings are consistent with those from Table 3. Additionally, we find that expected work involved in applying fertilizer was not regarded as important. With regard to social influence, we find that most respondents gave low ratings to the importance of their neighbors' influence. As to the institutional influence, only 69 farmers claimed that some kind of institution had made recommendations regarding fertilizer use and about 70% of them did not think the institutional influence had been important. Moreover, the goal of farming was solicited as it may be associated with fertilizer use intensity. The majority of farmers (92%) gave higher ratings to obtaining food from their own farming while 64% of them identified earnings as a farming goal. The two goals are certainly not mutually exclusive.

It is expected that farmers' subjective evaluations of factors in Table 4 and 5 affect their decisions on fertilizer use intensity. However, accounting for the effects of these subjective components in the regression models is a rather challenging task. No existing literature in fertilizer studies has dealt with it. For example, soil fertility may affect fertilizer use and it is usually assumed that the poorer the soil, the more fertilizer farmers use. This is based on the assumption that each farmer considers soil fertility when making the decision. However, if we know the importance score given to soil fertility by individual farmers, this assumption would not apply for those who rate soil fertility as unimportant to their decision making. If we combine these two pieces of information (fertility of soil and subjective evaluation) by multiplication, the effect of both factors will be taken into consideration in the model. The combined terms are calculated based on the subjective expected utility (S.E.U.) theory[xxvi] and in expectancy-value formulations.[xxvii] The expectancy-value theory has proved useful in the explanation of social behaviours and has been widely used in social psychology.[xxviii] According to this theory, individuals choose behaviors based on the outcomes they expect and the values they ascribe to those expected outcomes. In this study, the values correspond to the importance score of each decision variable given by the farmers. For those variables that have no importance scores, the underlying assumption is that they have the same level of importance for all the farm households. Combining the factors and importance ratings, several variables are included in the regression models. They include:

- Gain in crop yield × Importance: how the yield gain from fertilization weighted by importance score affects fertilizer use intensity. The hypothesis is that farmers would use more fertilizer if the gain and the importance are higher.
- Manure × Importance: how manure application weighted by importance score affects fertilizer use intensity. It is assumed that if more manure is applied and manure is important for the decision then less fertilizer is used.
- Soil fertility × Importance: how soil fertility weighted by importance score influences the amount of fertilizer application. The hypothesis is that higher fertility and higher importance lead to less fertilizer.

- Cost of fertilizer × Importance: how the cost of fertilizer (the price of urea) weighted by importance score affects fertilizer use. As the price of urea is similar, this term captures the effects of given importance on fertilizer use.

Capital availability is excluded due to the multicollinearity problem as it has a high degree of correlation with the cost. Fertilizer effectiveness is generally acknowledged by the farmers but a suitable indicator is not available to quantify it. Other variables are not included as a result of either low subjective significance or lack of variation in importance scores. It is worth noting that all the subjective variables were tested in the earlier stages of the models.

5. Regression results and discussion

Taking into account the factors identified in Sections 3 and 4, the regression models are estimated and the results are shown in Table 6. Model 1 considers farm and farmer related factors as well as subjective information while Model 2 considers only the former. The following interpretation and discussion will focus on Model 1. Model 2 is presented as a comparison.

With regard to personal attributes, the model results show statistically insignificant coefficients for the age and education variables. The insignificance of the education variable may be related to the complex role of education. On one hand, a higher level of education may facilitate fertilizer application by improving access to information on and knowledge of fertilizer. One the other hand, in a situation when nitrogen fertilizer is overused, better knowledge of fertilizer has the effect of neutralizing the tendency of overuse. This complexity, however, cannot be captured by a single-equation modeling framework because of the counteractive effects.[xxix] The dependent ratio is significant at 10%, suggesting that subsistence pressure from dependents positively influences the rate of fertilizer use. This is consistent with our hypothesis.

Regarding farmers' resources endowment, farm size appears significant at 5% and has a negative sign, implying that per hectare fertilizer use decreases with farm size. This reflects an increasing efficiency of fertilizer productivity as farm size increases. With respect to irrigation, the coefficient is positive and statistically significant at a 1% level. The result is not surprising because firstly, irrigation enables crops to absorb more fertilizer, which motivates farmers to apply a greater quantity. Secondly, the land connected to an irrigation canal or well is usually flat, easily accessible and has more secure yields under the condition of highly variable rainfall, thus farmers face lower risks when applying the input more intensively. The results show that if the farmer's entire land has access to irrigation, the fertilizer use is 86 kg/ha higher than farmers with no irrigated land.

	Model 1		Model 2	
Variables	Coefficient	t statistics[a]	Coefficient	t statistics[a]
Constant	680.69***	7.92	736.05***	8.84
Age	-1.56	-1.37	-1.37	-1.18
Education	-2.23	-0.5	-2.18	-0.48
Dependent ratio	91.88*	1.71	103.53*	1.81
Farm size	-104.27**	-2.51	-86.07**	-2.04
Irrigation	86.40***	3.43	121.76***	5.01
Manure			-1.08**	-2.25
Soil fertility			-51.95***	-3.18
Off-farm job	-17.41	-0.61	-12.27	-0.43
Agricultural assets	-0.01	-0.73	-0.004	-0.56
Hilly area	-0.50	-1.12	-0.32	-0.71
Distance	-10.12***	-2.67	-10.44***	-2.79
Fengning	79.69***	3.06	85.78***	3.33
Luanping	115.05***	3.45	131.34***	3.95
Gain in crop yield ´ Importance	0.02	0.90		
Manure ´ Importance	-1.75**	-2.45		
Soil fertility ´ Importance	-0.98	-0.09		
Cost of fertilizer ´ Importance	-63.03**	-2.41		
Goal of earning	88.85*	1.86		
R^2	0.27		0.24	
Number of observation	343[b]		343	

Table 6: Determinants of the intensity of total fertilizer use.[xxx]
***Significance at 1%, **Significance at 5%, *Significance at 10%.
[a]Calculated from robust standard errors using the Huber-White-sandwich estimator of variance.
[b]Several observations are removed due to missing data.

The two liquidity variables, off-farm work and household agricultural assets, do not appear significant, implying that farmers' decisions on fertilizer is not determined by liquidity. This is consistent with farmers' low ratings in the importance of cost and capital in Table 5. It is surprising that the share of hilly area is not correlated with fertilizer use. Distance from fertilizer market turns out to be highly significant, suggesting that in villages farther away, less fertilizer tends to be used. The regional dummy variables turn out to be highly significant and positive, indicating that the fertilizer level in Fengning and Luanping counties is considerably higher than the level in Chicheng county, which is the poorest among them. This is consistent with the reported statistics.

With regard to the combined terms taking account of subjective components from farmers, we find three of them are statistically significant. Manure as a

	Model 1[b]		Model 2[c]	
Variables	Coefficient	t statistics	Coefficient	t statistics
Constant	0.5	0.74	0.48	0.69
Age	-0.01	-1.02	-0.01	-1.31
Education	-0.06*	-1.81	-0.06*	-1.72
Dependent ratio	0.70	1.60	0.73	1.62
Farm size	-0.82***	-2.79	-0.81***	-2.66
Irrigation	0.68***	3.78	0.54***	2.91
Manure	-0.005	-1.21	-0.003	-0.65
Soil fertility	-0.24**	-2.06	-0.23*	-1.91
Off-farm job	0.28	1.06	0.32	1.18
c^2	42.79		35.86	
Log likelihood ratio	-185.15		-170.62	
Number of observation	347		347	

Table 7: Factors influencing farmers' overuse of nitrogen fertilizer (Probit[a]).
***Significance at 1%, **Significance at 5%, *Significance at 10%.
[a]The model takes 1 if the farmer overuses nitrogen and 0 otherwise.
[b]The number of overusers is 99 with the cutoff value of nitrogen of 450kg/ha.
[c]The number of overusers is 82 with the cutoff value of nitrogen of 500kg/ha.

combined term is significant at a 5% level and negative, which implies that manure plays an important role in farmers' decision making and generally offsets the use of chemical fertilizers. Despite the low ratings of importance of the cost of fertilizer, it appears significant in the model. Because of the similarity in fertilizer prices, this suggests that those few farmers who rate cost as important in their decisions apply significantly less fertilizer. In terms of farming goals, we find that the goal of earning is positively related to fertilizer use, indicating that farmers who prioritize earning tend to apply fertilizer more intensively. However, two other variables—the yield gain from fertilization and soil fertility—do not appear significant. The insignificance of yield gain implies that although important in farmers' decision making, it does not significantly affect the intensity of use. For soil fertility, this could be because of the counteractive influence from the soil variable and its importance.

As mentioned earlier, there exists a serious problem of overuse of nitrogen fertilizer in the study area. Now we turn to the investigation of this problem. A probit model is run to examine the effects of farm and farmer specific characteristics on the probability that an individual farmer over-fertilizes. The results in Table 7 show that education is significant and has a negative sign, which indicates that farmers with more years of schooling are less likely to overuse fertilizer. Educated farmers are more likely to be aware of the effects of fertilizers and to know the technical information that is necessary to use them effectively. Therefore, they tend to use appropriate amounts. This finding is supported by the literature. Focusing exclusively on farmers who overuse fertilizer, Ma[xxxi] found that education is negatively correlated with total fertilizer use (nitrogen dominant) in the North China Plain. Moreover, irrigation is found to contribute positively to overuse while farm size and soil fertility negatively influence overuse. Concerned with the uncertainty of model results to the threshold value, we performed the same econometric analysis with the cut-off point of 500 kg/ha in Model 2. The results are not sensitive to the change in the cut-off point.

6. Conclusions and policy implications

This study analyzes the factors affecting farmers' decisions on fertilizer use. Besides conventional farm and farmer related factors, it takes into consideration farmers' subjective evaluations in the models. From the farmers' points of view, their own experience, the growth and/or density of crop seedlings and yield gain from fertilization have been recognized as the most frequently considered factors in their decision making. The subjective evaluation of importance shows the high importance score of their own experience with fertilizer, yield gain from fertilization and effectiveness of fertilizer while low ratings of importance of the cost of fertilizer, capital availability, expected work in applying fertilizer and social influence. The low importance of social influence suggests that farmers in the study area received very little institutional support on fertilizer application and essentially make decisions on their own. The absence of guidance in determining appropriate levels of fertilizers for their land may have led to high levels of nitrogen fertilizer application.

The results from the regression model show that many of the subjective variables are significant, suggesting that the results would be biased without taking them into account.[xxxii] In general, irrigation, yield gain from fertilization and the goal of earning positively affect fertilizer use intensity while farm size, manure application, soil fertility and the distance to markets have a negative influence. Despite low importance scores, farmers who rate cost and expected work as important use significantly less fertilizer. The liquidity constraints play a trivial role in influencing fertilizer use, implying that farmers in this area make decisions independent of capital availability, partly due to low fertilizer prices. Investigation of the overuse problem shows that education significantly reduces the probability of overuse of nitrogen. This finding reveals that more education programs should be implemented to prevent farmers from overusing nitrogen fertilizers.

The role of education is clearly revealed in the analysis of the overuse of nitrogen but less explicitly in the analysis of determinants of fertilizer use. This study shows that fertilizer applications are largely outside the range of recommended balanced NPK levels. Many farmers expressed concern regarding the lack of understanding of land soil nutrient contents and stressed the importance of field soil experiments. These concerns imply that in this region, the education and extension services should concentrate on educating farmers about understanding their soil and recognizing the importance of balanced fertilizer application, fine-tuning their fertilizer use practices to improve the efficiency of fertilizer use, and on reducing the overuse of nitrogen. Improving rural extension services and on-site demonstrations will be beneficial to farmers by providing knowledge of soil quality and by raising awareness of the negative effects of excess fertilizer use. In the meantime, alternative methods of disseminating knowledge should also be explored. For example, one option is to provide technical training for fertilizer traders so that they may effectively disseminate fertilizer use information, including knowledge of balanced NPK applications, to farmers. This is extremely relevant in rural China as fertilizer traders have become the primary source of farmers' knowledge on chemical fertilizers.[xxxiii] As weather is important in deciding the quantity of fertilizer to use, provision of timely local weather forecasts would help farmers to evaluate the risks and determine the appropriate amount to apply.

To the authors' knowledge, there are limited education and training programs available particularly on fertilizer application in the study area. This reflects two observations that are generally the case in rural China: first, extension services have weakened since the agricultural extension reform launched in mid-1980s, and second, extension agents lack the initiative to provide technical guidance to farmers (especially on reducing the amount of fertilizers) due to lack of updated knowledge, budgetary constraints, and increasingly, pressure to sell fertilizers and other agricultural inputs to make ends meet. Policy changes are required in this area, in particular to address the need for disengaging the commercial interest of extension agents from the provision of extension services, and to train the agents to update and improve their knowledge base on the optimal and balanced use of fertilizers. In the meantime, it is important to take new forms of extension services, for example the model where these services are provided by specialized extension agencies and financed by farmer-based organizations such as commodity cooperatives.

Although this study has focused on China, the research methodology and survey techniques are highly relevant for studying similar problems in other regions, in particular South and Southeast Asia where smallholder farmers dominate and share characteristics with Chinese farmers. As fertilizer consumption continues to grow, imbalanced and excessive use of fertilizers and their environmental impact will become a major concern. It is necessary to investigate and better understand the factors determining farmers' decision-making concerning fertilizer use in order to come up with appropriate policies regarding prices, incentives, and future extension program priorities.

Further research could include studying more in-depth the overuse problem on a wider geographical scale. A question to consider, apart from lack of awareness on the part of the farmers and their strong desire to secure yields, are which driving factors and incentives have led farmers to continue over-fertilizing, and how some of the environmental costs that are presently external to farmers might be internalized through policies. It would also be interesting to extend the study to pesticide use, since it is experiencing similar growth and has the potential to very negatively impact the environment. Furthermore, new approaches to extension services need to be explored in which tailored information and guidance on balanced fertilizer use for specific crops can be effectively provided to farmers in different agro-climatic conditions.

End Notes

[i] China Agricultural Development Bulletin, 2007

[ii] Zhu and Chen, 2002

[iii] Zhu and Chen, 2002; Wang et al., 2005

[iv] Sun and Zhang, 2000

[v] Ford, 2007

[vi] Xing and Zhu, 2000; Wang et al., 2001; Wang and Cao, 2006

[vii] Wang et al., 2002

[viii] Wang et al., 2003

[ix] Feder et al., 1985; Adesina and Zinnah, 1993; Jha and Hojjati, 1993; Coady, 1995; Nkamleu and Adesina, 2000; Chianu and Tsujii, 2004; Abdoulaye and Sanders, 2005

[x] Kivlin and Fliegel, 1967; Nowak, 1992

[xi] Adesina and Zinnah, 1993; Adesina and Baidu-forson, 1995; and Sall et al., 2000

[xii] Ajzen and Fishbein, 1980; Johnson, 1987; Adesina and Baidu-forson, 1995; Öhlmér et al., 1998; Öhlmér and Lönnstedt, 2004

[xiii] Gao, 2000

[xiv] Qing et al., 2004

[xv] Ma, 2006

[xvi] Wooldridge, 2002

[xvii] Jha and Hojjati, 1993; Coady, 1995; Chianu and Tsujii, 2004; Abdoulaye and Sanders, 2005

[xviii] Adesina and Baidu-forson, 1995

[xix] Coady, 1995

[xx] Waithaka et al., 2007

[xxi] Freeman and Omiti, 2003

[xxii] Chianu and Tsujii, 2004

[xxiii] Jha and Hojjati, 1993; Abdoulaye and Sanders, 2005

[xxiv] Wang et al., 2006

[xxv]

[xxvi] Edwards, 1961

[xxvii] Fishbein & Ajzen, 1974; Palmgreen, 1984

[xxviii] van der Pligt & de Vries, 1998; Wigfield & Eccles, 2000

[xxix] It may be objected that if education facilitates fertilizer application in the low-use population and neutralizes the tendency of over-use in the high-fertilizer-use population, then this can be modeled by including a quadratic term for education in addition to the linear term. We have tried to include the quadratic term of education in the regression, but it appeared insignificant in all the cases. The reason might be that there is not a sufficient number of low fertilizer farmers in the sample to explain the counteracting effects. In fact the majority of farmers are using moderate to high amount of fertilizers in the study area. In addition, as explained in the paper, education is a somewhat complicated factor, whose effect cannot be simply modeled through a quadratic equation.

[xxx] See Table 3 for units of variables.

[xxxi] Ma, 2006

[xxxii] Omitted variable bias occurs when: 1) the omitted variable has an effect on the dependent variable and 2) the omitted variable is correlated with independent variable. Although the second point is not elaborated, the subjective variables considered in this paper have certainly correlation with personal attributes e.g. age and education etc.

[xxxiii] Ma et al., 2005

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