INTERNATIONAL CONFERENCE OF AGRICULTURAL ECONOMISTS
ICAE
29th | Milan Italy 2015
UNIVERSITÀ DEGLI STUDI DI MILANO AUGUST 8 - 14
AGRICULTURE IN AN INTERCONNECTED WORLD

Perception of Substandard Fertilizer and Its Impact on Use Intensity

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Abstract

Poor quality fertilizer is a growing problem in many countries. This is of special concern to smallholder farmers as they have neither the buying power nor the testing instruments to verify the authenticity of the input. We analyze the effect of fertilizer quality on its use intensity. This study distinguishes between perceived quality and true quality. Results show that perception of higher quality reduces fertilizer application rates. However, the true quality measure based on laboratory testing of fertilizer samples has no statistically significant impact on fertilizer use intensity. There is also no significant correlation between true and perceived quality.

1. Introduction

Since the 1960s, the value of world agricultural output has increased at an average rate of 2.3% per year, staying ahead of the annual population growth rate of 1.7% (Wik et al., 2008). A major factor for this high agricultural output growth rate has been increased input use, which accounts for about 60% of the growth, with total factor productivity being responsible for the other 40% (Fuglie and Nin-Pratt, 2013). In addition to improved genetic material, irrigation and mechanization, the level of fertilizer usage has gone up from less than 25 kg per hectare in the early 1960s in all regions of the world, to almost 200 kg per hectare in East Asia and Pacific and to more than 100 kg per hectare in South Asia in the early 2000s (Wik et al., 2008; Fuglie, 2010).

Although the rise in fertilizer use has helped promote output growth (Fan and Pardey, 1997), its overuse has also led to negative outcomes such as biodiversity losses, eutrophication, air pollution, and nitrate contamination of water resources (Yadav et al., 1997; He et al., 2007; Liu et al., 2013). In a comprehensive five-year study conducted by the China Academy of Geological Sciences from 2006 to 2011, a total of 7,451 groundwater samples were collected in the North China Plain and tested. The results show that only 25% of the samples are safe for direct human consumption, which is lower than the national average of 45% (Jiang and Jiang, 2013). One of the causes is the overuse of chemical fertilizer, as Chen et al. (2005) and Hu et al. (2005) show that nitrate pollution in groundwater is a problem in the region.

In addition to its overuse, the true content of this agricultural input is another growing issue in many countries. The problem of low quality or fake fertilizer seems to be quite widespread and has been found in news reports of various countries, such as Bangladesh (Zahur, 2010), Cambodia (Hamaguchi, 2011), China (Deng, 2012), Nigeria (Liverpool-Tasie et al., 2010), Tanzania (Kitabu, 2013), Vietnam (Phien, 2013), and Zambia (Mwebantu New Media, 2012). This is of special concern to smallholder farmers as they have neither the buying power nor the testing instruments to verify its authenticity. A focus in the literature has been on determining the different factors and policies that affect fertilizer use intensity (Babcock and Hennessy, 1996; Lankoski and Ollikainen, 2003; Pufahl and Weiss, 2009; Alem et al., 2010; Duflo et al., 2011). However, the quality of the input itself has yet to be examined as a potential factor.

Farmers' perception of fertilizer quality can be influenced by both the expectation about its true nutrient content and the expectation about the efficiency of fertilizer in general. As can be seen in the abovementioned news reports, trust in fertilizer content is an issue existing mainly in the developing world. However, the problem of different expectations about fertilizer efficiency affects farmers in both developing and developed countries. Some farmers might apply more fertilizer if they feel that the suggested rate is too low, even if they trust the labeled nutrient level. The analytical framework in Section 2 is appropriate for both types of expectations but due to data availability, we focus our empirical analysis in Section 4 on uncertainty about true nutrient content and examine how fertilizer quality affects the intensity of fertilizer application.

We use two different types of quality measurements for fertilizer: the perceived quality according to farmers' opinion and the true quality based on laboratory testing. Data on household characteristics and farm production were collected in a household survey. Farmers were also asked about the quality of the main fertilizer they use. In addition, we collected samples of their main fertilizer which were later tested in a laboratory. We then analyze how these two different measures of fertilizer quality affect the level of fertilizer use and examine whether the two effects are similar. Determining the link between true quality, perceived quality, and fertilizer application rates is important because it can help to guide policy in lowering the use of fertilizer. This provides not only private benefits to farmers in reducing farm input costs, but also public benefits in alleviating the environmental problems caused by nitrate leaching of fertilizer.

2. Model

To examine how quality uncertainty affects the level of fertilizer application, we construct a model based on Zellner et al. (1966). We add an extra term e^z to capture the true fertilizer content, similar to the way Zellner et al. include the production error term into their function: $Y = A(e^z F)^{\alpha_1} X^{\alpha_2} e^{\epsilon}$, with Y as output, A as total factor productivity, F as fertilizer, X as another input, α_1 and α_2 as elasticities, and e^{ϵ} as production error term. In this case, F is the labeled content of fertilizer, while $e^z F$ is its true content. As the fertilizer manufacturer reduces the ingredients to save costs, the true content is lower than the labeled content, and the term e^z is therefore bound between zero and one. This means that the value of z can range from negative infinity to zero. The lowest end of the range is reached when the fertilizer is fake, while the highest end represents the case in which the true content is the same as the labeled content on the fertilizer package.

When farmers decide the amount of inputs to apply, they do not know for certain the level of output they will be able to harvest. The input decision is thus based on what would maximize their expected profit assuming risk neutrality. They do not know the true content of fertilizer either, thus it is the expected content of fertilizer that influences their decision making: $E(\pi) = p_y E(Y) - w_f E(e^z F) - w_x X$. The other terms in the optimization equation are p_y, w_f and w_x, which represent output and input prices, respectively. In addition to uncertainty about fertilizer content, farmers' perception of e^z can also be affected by expectations about the efficiency of fertilizer in general. Solving for the first order conditions with respect to the two inputs, F and X, we find that the optimal decisions of farmers for how much fertilizer and other inputs to apply to be

$$\ln Y - \ln F = k_1 + \alpha_1 z + (1 - \alpha_1)E(z) + \epsilon + \gamma_1, \tag{1}$$

$$\ln Y - \ln X = k_2 + \alpha_1 z - \alpha_1 E(z) + \epsilon + \gamma_2, \tag{2}$$

with k_1 being $\ln\left(\frac{w_f}{p_y \alpha_1}\right)$, k_2 being $\ln\left(\frac{w_x}{p_y \alpha_2}\right)$, and γ_i being the stochastic error term of the use of input i. The model is a basic construct for two inputs, yet can be extended to include more inputs as well.

Combining Equations (1) and (2) with the production function, we can solve for the optimal decision of fertilizer use:

$$\begin{aligned}\ln F = (1 - \alpha_1 - \alpha_2)^{-1}[&\ln A - (1 - \alpha_2)(k_1 + \gamma_1) - \alpha_2(k_2 + \gamma_2) \\ &- \alpha_1(1 - \alpha_1)(1 - \alpha_1 - \alpha_2)E(z) - \epsilon].\end{aligned} \tag{3}$$

We examine from Equation (3) the effect of a change in expected fertilizer quality on the level of fertilizer use, which is given by

$$\frac{\partial F}{\partial E(z)} = -\alpha_1(1 - \alpha_1)F. \tag{4}$$

If fertilizer use is non-zero, then the direction of the effect in Equation (4) depends on the production elasticity of fertilizer, α_1. The effect is positive if the elasticity is high. In this case, a higher expected fertilizer quality would increase the fertilizer application rate. If the production elasticity of fertilizer is low, which is usually the case when input use is very high, for example in North China Plain, then the effect in Equation (4) is negative. Thus, an increase in $E(z)$ (that is its value becomes less negative) would lead to a lower level of F. In other words, perception of higher fertilizer quality decreases the amount of fertilizer being applied.

If we repeat the same analysis for Equation (3) with respect to true fertilizer quality instead of expected quality, we obtain the following expression which shows that the true quality of fertilizer affects the level of fertilizer use through its expected quality:

$$\frac{\partial F}{\partial z} = -\alpha_1(1-\alpha_1)F\frac{\partial E(z)}{\partial z}. \tag{5}$$

The direction of the effect depends on the link between true and expected quality. If the link is positive (negative), true and expected quality would have the same (opposite) directional effect on fertilizer use. It is also possible that true quality has no effect on fertilizer application rates, which would occur if there is no correlation between true and expected fertilizer quality.

3. Data

The data consists of two main parts: the first is from a household survey and the second is from the laboratory testing of fertilizer samples. The spread of information plays a critical role for perception. With this in mind, household survey data and fertilizer samples were collected from a township in North China Plain that included villages with structured extension services and those without, so that we can compare if there are differences between these two types of villages.

3.1. Household Survey

We conducted a household survey in the Disituan Township of China in 2012. The township is located in the southern part of Hebei province and has a population of about 40 000 people living in 40 villages (Jin Nong Wang, 2002). The China Agriculture University (CAU) has a research station within the township. Since 2007, the university expanded its activity from running field experiments at the research station to establishing centers in the Disituan Township and other townships to conduct training sessions for local villagers and to spreading information on good farming practices, including the appropriate amount of fertilizer to apply. Five villages were chosen for our survey based on whether they had an extension service center and their distance from the CAU research station. The first is a village in the Disituan Township with an extension service center. A CAU student lives at the center full-time and the villagers could visit him if they had questions. The other four villages consist of two villages that are located near the CAU research station and two villages that are located in the two corners of the township farther away from the research station. These four villages have no extension service center within the village.

Twenty households were randomly selected from each of the five villages. As six of these originally selected households could not be reached after three visits, we resampled other households from their same villages to ensure that 20 households had been interviewed in each village. Therefore, the total sample consists of 100 observations. In order that the production and fertilizer use data collected from different households could be compared with one another, we focused on one crop. Maize was chosen because it is the main grain crop in the region. In terms of fertilizer, we recorded data for all the fertilizer that farmers used during the 2012 summer maize growing season. These included the brand, content, price and application rate for each type of fertilizer applied to maize. The content information consisted of the share of nitrogen (N), phosphorus (P), and potassium (K) in the fertilizer according to the label on the package. We requested to see the fertilizer package to confirm the information, as most farmers did not know or could not remember the exact share of the three elements in their NPK fertilizer. We asked farmers to give a score (between zero and ten inclusive) for their fertilizer based on its quality, with the lowest score of zero being given to fake fertilizer. When farmers applied more than one fertilizer to maize, we asked them to give the score based on the most-used fertilizer. This score constituted the perceived fertilizer quality in our analysis.

3.2. Fertilizer Testing

During our survey, we collected fertilizer samples from the households and tested them at a third-party private laboratory[1] to construct a measure of true fertilizer quality. Similar to perceived fertilizer quality, the score of true quality is based on the most-used fertilizer of a household for maize production. We assigned a score to 47 households based on the test results of their own fertilizer. The remaining households had no leftover fertilizer for us to collect and were given a score based on fertilizer samples collected from other households. If possible, we gave these households the true quality measure from fertilizer with the same brand and content; however, in cases where that was not possible, we applied the true quality score from other fertilizers of the same brand. At the end, 86% of households have a measure of true fertilizer quality. The remaining households did not have leftover fertilizer for us to collect and their brands were different from other collected samples.

The two main aspects that distinguish one fertilizer from another are the amount of nutrients they contain and the availability of these nutrients to plants (Vitosh, 1996). We use these criteria to construct two separate measures of true fertilizer quality. The first is whether the actual content of the fertilizer matches the amount of nutrients labeled on the package. In this case, we choose to focus on nitrogen because it is the major fertilizer element used in the region and appears in the main fertilizer of every household. The mean of the distribution is about 0.71, that is on average only 71% of the labeled nitrogen content is contained in the fertilizer. In addition, the true nitrogen content is lower than the labeled level in the fertilizer of 90% of the households. These findings are similar to those of Boeber et al. (2009), who tested 14 fertilizer samples collected from the southern part of Hebei province in 2008. They find that 12 of the samples have less nitrogen than the labeled amount, with the mean of the true content at around 80%. There is also news coverage on the severity of this issue in the region (Wang, 2011), where USD 47.22 million of fake agricultural input including 220,000 tonnes of fertilizer was confiscated in China in the first six months of 2012 (Deng, 2012).

The second measure of fertilizer quality reflects how much of the contained element is actually available to the crops. Due to the many different sources of fertilizer and their varied solubility, it is possible that

[1]The analysis methods used by the laboratory are as follows: determination of total nitrogen content by dry combustion according to the method DIN ISO 13878; determination of total phosphorus content by Inductively Coupled Plasma Emission Spectrometry according to the method DIN 38406 part 22; and determination of available phosphorus content by calcium acetate lactate extraction according to the method VDLUFA A6.2.1.1.

fertilizer may have the amount of content indicated by the label on the package, but that the nutrients may not be readily available to be absorbed by plants. For this analysis, we focus on an element other than nitrogen because nitrogen is a nutrient with high availability (Vitosh, 1996). Instead, we analyze the second most common element contained in fertilizers in the study area, phosphorus. According to Kratz et al. (2010), the availability of phosphorus can be roughly separated into three groups: immediately available, available during the first vegetation period, and the total amount that is or might become available in the long-term. The first group is a subset of the second group, which, in turn, is a part of the third group. We define our second measure of true fertilizer quality as the ratio of nutrient that is available during the first vegetation period to the total nutrient that is available or may become available in the future. In our research region, the fertilizer quality measure of phosphorus availability ranges from zero to 0.8. The mean of the distribution is about 0.47, that is the availability of phosphorus to plants is about 47%.

4. Empirical Analysis

We examine empirically how perceived fertilizer quality and true quality affect the intensity of fertilizer use. Table 1 provides a summary of the variables included in our regression analysis.

[Table 1 about here.]

There are two different measures of fertilizer intensity adopted in this study. The first is the total fertilizer applied per unit of land for summer maize production. As we also have a more precise measurement of fertilizer intensity in the form of total nitrogen applied per unit of land, we rerun the same analysis with this new dependent variable to examine whether there are any differences in the results.

The remaining variables can be grouped into two categories: fertilizer quality measures and the control variables that could affect fertilizer use intensity. These variables include human, natural, social, and financial capital that affect the ability of a household in pursuing various livelihood strategies (Scoones, 1998). Awareness about issues related to fertilizer overuse, such as wastage and environmental degradation, and receptiveness to changes are parts of human capital that could affect fertilizer use intensity. Therefore, we expect that farmers with higher education and those who are more willing to try new inputs to be more receptive to the idea of reducing fertilizer use. The size of maize production area is used to represent natural capital. Farmers with less land are expected to crop more intensively and use more fertilizer, as they have to extract as much output as possible from the limited land that they have. For social capital, we use the presence of household members on village committee and contact with extension service to capture the networking possibilities of each household. Financial capital includes variables such as total household income, maize output used for own consumption, and total insurance expenditure. Total income reflects farmers' ability to buy the input. In addition, households who use the crop mainly for own consumption are expected to apply more fertilizer as they need the harvest for subsistence. Households with lower insurance expenditures could also use more of the input because they are less protected by a contingency plan in case of crop failure.

From the literature on fertilizer demand, transaction cost such as that from travel and transportation is another important aspect in analyzing fertilizer demand (Key et al., 2000; Winter-Nelson and Temu, 2005). We include in the regression the farthest travel distance between the household and the farm, and expect it to have a negative influence on fertilizer use. Ricker-Gilbert et al. (2011) and Liverpool-Tasie (2014) examine the impact of access to subsidized fertilizer. This is probably less of a determining factor in our research area because it is the production of the input that is subsidized and thus the farmers can buy the low price fertilizer from the market (Cheng et al., 2010). As all farmers in our survey sample use fertilizer, we include the price variable as a control for access to cheap input. We also include other factors of maize production in the regression, such as labor, seed, and organic fertilizer. The first two inputs are expected to move in the same direction as fertilizer because a household who farms more intensively is likely to use more fertilizer as well. Organic fertilizer acts as a substitute for chemical fertilizer, thus we expect farmers who use organic fertilizer to decrease their application of chemical fertilizer.

The three fertilizer quality measures are the perceived quality by farmers and two true quality measures based on laboratory tests of fertilizer for its nitrogen content and phosphorus availability. Table 2 shows the pairwise correlation between these measures.

[Table 2 about here.]

It is no surprise that the two variables for true fertilizer quality are significantly correlated. This means that a fertilizer with true nitrogen content that is close to that which is labeled on the package also tends to contain phosphorus that is highly available to the crops. A more surprising result is that there is no significant correlation between the perceived fertilizer quality and the true fertilizer quality based on laboratory testing, be it nitrogen content or phosphorus availability. In other words, farmers themselves have no idea about the true quality of fertilizer. We include both the perceived and true indicators in our regression analysis to look at their impact on fertilizer intensity. As mentioned earlier, extension service may play an important role in farmers' perception of fertilizer quality and input use decision. We examine this effect by adding an interaction term between fertilizer quality and contact with extension agents. Dummy variables that indicate whether a household is located in a village with an extension service, near the CAU research station, or without either of these facilities are also included.

5. Results

We examine the factors that affect fertilizer use intensity in this empirical analysis. For the dependent variable, we first consider the weight of fertilizer applied rather than the amount of nitrogen applied. As the error term is not normally distributed, we run the regression with the Huber-White robust standard errors. The results are shown in Table 3. The three columns represent separate regressions with the same control factors, but each of them has a different fertilizer quality indicator: the perceived quality by farmers, the true quality based on nitrogen content, and the true quality based on phosphorus availability.

[Table 3 about here.]

From the control factors, greater household income and stronger dependency on the crop for own consumption lead to an increase in fertilizer use intensity. On the other hand, willingness to change input use patterns, larger land area, higher insurance expenditure and fertilizer price, and the use of organic fertilizer lower the application rate of chemical fertilizer. The price effect disappears in the second and third columns of Table 3 due to the highly significant correlation between the price and the true fertilizer quality variables.

As the pairwise correlation between price and self-assessed fertilizer quality is not significant, the price effect is observable in the first column of the table. From the three different measures of fertilizer quality, only one of them has a significant impact on input use intensity. Farmers who perceive their fertilizer to be of a higher quality apply less fertilizer, while those who believe that the quality is worse compensate by applying more. Both of the true fertilizer quality indicators have no statistically significant effect on fertilizer use intensity. To confirm that this lack of significance is not due to the correlation between true quality and price, we rerun the same regression without the price variable. The coefficients of true fertilizer quality remain insignificant, regardless of whether the price variable is included in the regression.

A potential issue with this analysis is the endogeneity caused by unobservable farmers' characteristics, such as farming ability or familiarity with fertilizer, which could affect farmers' perception of fertilizer quality and decision on use intensity. Thus, we repeat the regression with additional control variables. Farmers' age and percentage of income from agriculture are included as proxies for experience and ability in farming. The reasoning is that as our research area is an agricultural society and the villagers start to work in the field since they are very young, farmers who are older and who receive most of their income from agriculture have more experience in farming and greater ability that comes with practical knowledge. We include also the length of time that the farmers have been using their current brand of fertilizer, as a proxy for experience with the fertilizer that they use.

[Table 4 about here.]

By comparing Column (1) in Table 3 and Column (1a) in Table 4, we see that the main results remain consistent, with the self-assessed fertilizer quality having a negative and statistically significant effect on fertilizer use. We repeat the same analysis with true fertilizer quality and find that the outcome also remains consistent, with both of the true quality measures being statistically insignificant in determining fertilizer intensity. Another possible concern with the analysis is that there is a reverse causation effect, as fertilizer use intensity affects output and this, in turn, influences farmers' perception of fertilizer quality. A mitigating factor for this problem is that the coefficient of perceived quality is negative while the abovementioned reverse causation effect is positive if higher fertilizer intensity increases output, which then improves farmers' perception of fertilizer quality. It means that the negative impact of perceived quality on fertilizer intensity is strong because the coefficient remains statistically significant and negative despite the positive feedback effect.

It is possible to argue that measuring fertilizer intensity by aggregating the weight of all fertilizer is imprecise because it includes fertilizer of various types and nutrient contents. Therefore, we repeat the regressions with the same set of independent variables but with a more precise representation of fertilizer intensity as the dependent variable. We focus on just one nutrient and we choose the most commonly used fertilizer nutrient in the region, which is nitrogen. The main difference in the results is that the regression coefficients become less significant in general. In addition, all fertilizer quality variables are statistically insignificant, including perceived quality which was significant in the regression shown in Tables 3 and 4. This means that perception of lower quality increases the intensity of fertilizer use in weight, but it has no statistically significant effect on nitrogen use intensity. This is probably because many farmers are not aware of the nutrient content in their fertilizer. In our study, all households could remember the total weight of fertilizer applied, but only five knew the exact share of the three main nutrients in their NPK composite fertilizer. This raises a question on the appropriate choice of the dependent variable. Scientifically, the nutrient content and type of fertilizer are very important factors that need to be considered in a production analysis. However, when farmers are not aware of these differences, it could be more appropriate to use a less precise measurement if the purpose of the analysis is to explain actual observed behavior. Needless to say, this depends on the situation of each research region as the choice for a precise measurement is clearly preferred if farmers are more aware of fertilizer nutrients they apply.

The results from this empirical study suggest that when farmers think that fertilizer is of low quality, they compensate by applying more. However, when the true nitrogen content is actually lower than is labeled, there is not any significant impact on farmers' action, neither in the total fertilizer applied nor in the total nitrogen used. These responses are as reflected in Equations (4) and (5). Equation (4) shows that an increase in perceived quality lowers the use level when the output elasticity of fertilizer is low. This condition applies to our research region in China as the country has a high fertilizer usage and the production elasticity of this input is very low or close to zero, especially in maize production (Tian and Wan, 2000; Chen et al., 2003). Equation (5) indicates that true quality only affects fertilizer use through perceived quality. If there is no correlation between perceived quality and true quality, as shown in Table 2, then there is no effect of true quality on the fertilizer application rate. A possible explanation for this phenomenon is that farmers are not able to assess the quality of fertilizer in our study area. Farmers there do not have the equipment to perform tests and it is difficult to determine the quality of fertilizer from crop output alone as there are many other factors that could affect output. It was observed that farmers switch fertilizer quite frequently, with the average farmer switching once every 2.8 years. When asked how they choose a particular fertilizer when they switch to a new one, 45% said that it is according to recommendations by fertilizer sellers and another 27% said that they follow other farmers.

[Table 5 about here.]

This means that for about three-quarters of the surveyed households, fertilizer choice depends on what others tell them. It is thus likely that word of mouth rather than the true fertilizer quality, which cannot be easily observed, plays an important role in shaping farmers' perception of fertilizer quality.

In the next part of the analysis, we examine how extension service affects the previous regression outcome. Villages in our survey can be grouped into three categories: those with an extension service (group A), those without an extension service but that are located near the research station (group B), and those without an extension service or nearby research station (group C). We create three dummy variables, each representing one of the three village categories, and include the group A and group B dummy variables into the regression, with group C acting as the reference category. We show the coefficients of the variables of interest in Table 6.

[Table 6 about here.]

In order to examine whether contact with extension service affects the previously observed impact of fertilizer quality on use intensity, we calculate the marginal effect based on the coefficients of the interaction terms.

[Table 7 about here.]

The results in Table 7 indicate that as was found before, the only quality indicator with a statistically significant effect on fertilizer intensity is perceived quality, and not the true quality. However, this negative marginal effect is significant only for farmers who have no contact with the extension service in the past three years. For farmers who have met with the extension agents during this period of time, their perception of fertilizer quality has no significant impact on their fertilizer use intensity. This could be because these farmers have information from the extension service regarding the amount of fertilizer to apply, thus their input use decision is based more on these recommendations rather than their own perception of fertilizer quality. The village type dummies are mostly statistically insignificant, except in one case where farmers from villages near the research station (group B) have a lower fertilizer use intensity than the farmers from the reference category (group C), that is villages without an extension service or nearby research station. One possible reason that the dummy variable for group A villages is not statistically significant despite the presence of an extension service could be that the service is a relatively new initiative in the last five years, whereas the research station which is nearby group B villages has been there since the 1970s.

6. Conclusions

In analyzing the link between fertilizer quality and use intensity, we distinguish between perceived quality and true quality. We examine how the results differ depending on the quality measure. Based on the theoretical model, perception of higher fertilizer quality by farmers leads to a lower application rate if the production elasticity of fertilizer is low. On the other hand, the true quality of fertilizer affects use intensity only through perceived quality. If there is no link between true and perceived quality, then true quality has no effect on fertilizer use intensity. We conduct a household survey to collect data for the empirical analysis, which includes a self-assessment of fertilizer quality by farmers and the collection of fertilizer samples from them to be tested in a laboratory. Results show that perception of higher fertilizer quality reduces its application intensity. However, there is no significant correlation between the perceived and true quality, and both of the true fertilizer quality measures (nitrogen content and phosphorus availability) have no significant effect on fertilizer use.

Farmers in our research region, who believe that their fertilizer quality is low, compensate by increasing the total weight of their fertilizer use. Based on this finding, one would expect that when the true nitrogen content of a fertilizer is lower than that which is labeled on the package, the farmers would compensate by applying more nitrogen. However, we find no such effect. The only fertilizer quality variable that affects use level is the perceived quality by farmers and it has an impact solely on fertilizer intensity by total weight. Both true quality and perception of quality have no influence on the intensity of nitrogen use. This could be due to the low awareness of farmers on the nutrient content of their fertilizer and the lack of correlation between true and perceived quality. Our research provides insight into the issue of questionable fertilizer quality, especially how perceived quality differs from true quality, and which of them has a real impact on fertilizer use intensity. This analysis could be improved and extended by including more households over a longer period of time. In addition, to examine whether there is a difference in farmers' reaction in a region with low fertilizer application, this study could be repeated in another region that is also affected by fertilizer quality problems but has low use intensity and high production elasticity for fertilizer.

Uncertainty about fertilizer quality is an issue in many countries and it is a growing problem. Therefore, it is crucial to examine how it affects fertilizer use decision, especially since fertilizer is an input that is overused in some countries and underused in others, which can lead to health and environmental degradation in the former and low production in the latter. Our study shows that low fertilizer quality increases application intensity in our study area, which is a major problem in North China Plain because it already has a high fertilizer use rate. It is thus important that policies and institutions help counter this problem, such as through a sector-wide monitoring body, a third-party testing service of the input, or more extension service manpower and facilities. It works to the advantage of the honest fertilizer manufacturers to contribute financially to the formation of the abovementioned testing services. This would help prevent their image from being tarnished by the unscrupulous manufacturers, as long as such services remain independent. This could reduce farmers' doubts about fertilizer quality, which is an important factor in reducing fertilizer use intensity.

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Table 1. Descriptions of variables

Description	Mean	Standard deviation
Use intensity of all fertilizers for summer maize (kg per mu[a])	66.45	36.43
Nitrogen use intensity for summer maize (kg per mu)	14.36	7.18
Education level of household head (year)	8.79	2.67
Percentage of land for trial of new fertilizer recommended by other villagers	75.47	30.03
Area of planted land for summer maize (mu)	6.66	5.65
Household member on the village committee (1=yes, 0=no)	0.10	0.30
Contact with extension service in the past three years (1=yes, 0=no)	0.29	0.46
Annual household income (thousand yuan)	23.29	12.82
Maize output used for own consumption (thousand kg)	0.18	0.67
Total household insurance expenditure (thousand yuan)	0.88	1.24
Distance from house to the farthest farm plot (km)	1.48	0.57
Price of the main fertilizer for summer maize (yuan per kg)	3.01	0.68
Labor use intensity for summer maize (day)	16.39	17.50
Seed use intensity for summer maize (thousand per mu)	4.68	0.89
Organic fertilizer for summer maize (1=yes, 0=no)	0.15	0.36
Age of household head (year)	46.57	11.30
Percentage of total income from agriculture	61.08	27.79
Length of time using the current brand of fertilizer (year)	2.75	2.35
Self-assessed fertilizer quality by farmers (0 to 10; 10=best)	8.60	1.39
True fertilizer quality from test on nitrogen content (0 to 1; 1=best)	0.71	0.18
True fertilizer quality from test on phosphorus availability (0 to 1; 1=best)	0.47	0.29

Note: Summary statistics are calculated from all 100 observations in our survey.

[a] 15 mu = 1 hectare.

Table 2. Pairwise correlation between the different fertilizer quality measures

	Perceived quality by farmers	True quality (nitrogen)
True quality (nitrogen)		
Pearson correlation	−0.1674	
Spearman's rank correlation	−0.0155	
True quality (phosphorus)		
Pearson correlation	−0.0487	0.4610***
Spearman's rank correlation	0.0205	0.4434***

Note: Triple asterisk (***) denotes significance at 1%. The other coefficients are not significant at 10%.

Table 3. Regression coefficients on fertilizer use intensity for summer maize

Variable	(1)	(2)	(3)
Education level of household head	−0.159	−0.585	−0.547
	(1.170)	(1.158)	(1.197)
Percentage of land area for trial of new fertilizer	−0.381**	−0.442**	−0.442**
	(0.160)	(0.190)	(0.198)
Area of planted land for summer maize	−2.718**	−3.114**	−3.182**
	(1.355)	(1.562)	(1.547)
Dummy indicating household on the village committee	14.897	6.820	3.405
	(10.243)	(11.105)	(11.489)
Dummy indicating contact with extension service	−0.256	−4.130	−2.775
	(7.472)	(8.786)	(9.027)
Annual household income	0.883**	0.903*	0.939*
	(0.427)	(0.462)	(0.474)
Maize output used for own consumption	5.958*	6.041*	5.958**
	(3.373)	(3.077)	(2.776)
Total household insurance expenditure	−6.975*	−9.967**	−9.764**
	(3.609)	(4.456)	(4.307)
Distance from house to the farthest farm plot	1.037	−2.040	−3.152
	(5.619)	(7.088)	(8.057)
Unit price of the main fertilizer for summer maize	−11.808***	−14.914	−18.398
	(3.701)	(10.347)	(11.633)
Labor for summer maize	1.015	1.104	1.193
	(0.647)	(0.722)	(0.804)
Seed for summer maize	−0.176	−2.863	−2.680
	(3.499)	(3.682)	(3.726)
Dummy indicating organic fertilizer for summer maize	−20.415*	−20.105*	−21.892*
	(10.468)	(11.394)	(12.313)
Self-assessed fertilizer quality by farmers	−5.622**		
	(2.215)		
True fertilizer quality (nitrogen content)		−13.004	
		(22.523)	
True fertilizer quality (phosphorus availability)			−14.691
			(21.365)
Observations	100	86	86
R-squared	0.370	0.359	0.364

Note: Robust standard errors are in parentheses. Asterisk (*), double asterisk (**), and triple asterisk (***) denote significance at 10%, 5%, and 1%, respectively.

Table 4. Regression coefficients on fertilizer intensity with alternative specifications

Variable	(1a)	(1b)
Education level of household head	0.443	0.544
	(1.342)	(1.374)
Percentage of land area for trial of new fertilizer	−0.364**	−0.338**
	(0.160)	(0.163)
Area of planted land for summer maize	−2.998**	−3.149**
	(1.427)	(1.441)
Dummy indicating household on the village committee	11.180	9.392
	(10.023)	(10.854)
Annual household income	1.154**	1.118**
	(0.524)	(0.517)
Maize output used for own consumption	6.900*	6.160*
	(3.717)	(3.684)
Total household insurance expenditure	−6.602*	−6.664*
	(3.548)	(3.612)
Distance from house to the farthest farm plot	−1.627	−2.281
	(6.125)	(6.738)
Unit price of the main fertilizer for summer maize	−12.361***	−13.800***
	(3.848)	(3.964)
Labor for summer maize	0.939	0.986
	(0.599)	(0.603)
Seed for summer maize	−0.270	−1.334
	(3.771)	(4.008)
Dummy indicating organic fertilizer for summer maize	−21.620**	−19.863*
	(10.433)	(10.076)
Age of household head	−0.223	−0.213
	(0.371)	(0.376)
Percentage of total income from agriculture	0.264	0.255
	(0.182)	(0.182)
Length of time using the current brand of fertilizer	−0.559	−0.221
	(1.030)	(1.049)
Dummy indicating contact with extension service	−1.135	−43.934
	(7.587)	(42.883)
Self-assessed fertilizer quality by farmers	−5.393**	−5.665**
	(2.296)	(2.237)
Extension service dummy × self-assessed fertilizer quality		4.879
		(4.882)
Observations	100	100
R-squared	0.396	0.406

Note: Robust standard errors are in parentheses. Asterisk (*), double asterisk (**), and triple asterisk (***) denote significance at 10%, 5%, and 1%, respectively. The coefficients for the village type dummy variables of Column (1b) are shown in Table 6.

Table 5. Main factors determining which fertilizer to use

Factor	Percentage[a]
Recommended by fertilizer sellers	45
Follow other farmers	27
Own experience[b]	13
Recommended by extension service	10
Fertilizer price	4
Random	1

Note: [a] Percentages are calculated from all 100 observations in our survey.

[b] Reasons given under this factor include appearance of the fertilizer, such as the color and size of its granules.

Table 6. Selected regression coefficients on fertilizer use intensity after including an interaction term between fertilizer quality and contact with extension service

Variable	(1b)	(2b)	(3b)
Dummy indicating group A villages	−2.673	−11.191	−6.811
	(10.425)	(11.239)	(10.861)
Dummy indicating group B villages	−8.964	−12.745	−15.082*
	(7.077)	(9.891)	(9.033)
Dummy indicating contact with extension service	−43.934	−66.590*	7.607
	(42.883)	(39.741)	(17.457)
Self-assessed fertilizer quality by farmers	−5.665**		
	(2.237)		
True fertilizer quality (nitrogen content)		−32.894	
		(31.014)	
True fertilizer quality (phosphorus availability)			−8.096
			(23.805)
Extension service dummy × fertilizer quality	4.879	91.219*	−18.522
	(4.882)	(49.258)	(31.845)

Note: Robust standard errors are in parentheses. Asterisk (*) and double asterisk (**) denote significance at 10% and 5%, respectively. Column (1b) here is the same regression as the Column (1b) in Table 4. Other than the different measures of fertilizer quality, Columns (2b) and (3b) include the same variables as Column (1b).

Table 7. Marginal effect of fertilizer quality on use intensity after including an interaction term between fertilizer quality and contact with extension service

Variable	Contact with extension service	
	Yes	No
Self-assessed fertilizer quality by farmers	−0.786 (4.335)	−5.665** (2.237)
True fertilizer quality (nitrogen content)	58.325 (39.338)	−32.894 (31.014)
True fertilizer quality (phosphorus availability)	−26.618 (24.506)	−8.096 (23.805)

Note: Robust standard errors are in parentheses. Double asterisk (**) denotes significance at 5%. Calculations are based on the regression output in Table 6.