Effects of nitrogen fertilizer management on maize yield and nitrogen use efficiency: Based on farmer Survey in Quzhou county, North China Plain

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Abstract

The farmer survey was conducted in Quzhou county, Hebei province of China in three villages (Wang Zhuang, Xing yuan, and Sitton) with the objectives of elucidating the effects of nitrogen fertilizer (N) on maize production and nitrogen use efficiency (NUE). A total of 61 maize producers were randomly selected and interviewed. The educational level result revealed that about 8% of sampled farmers have no formal education, 11.6% have a basic level education, 21.6% have completed the middle-level education, and 58.3% have upper-level education. Most producers use nitrogen (40%), then phosphorus fertilizer (25%), and thirdly the compound fertilizer NPK, the least used fertilizers in the region are potassium and organic fertilizers such as straw and vegetable remains. The farmer applies twice, at base planting and in vegetative tasselling (VT), also, fertilizer N is the most used by farmers, whose application rates were higher ranging from 375 kg ha^{-1} representing 49.2%, followed by 300 kg ha^{-1} representing 39.3%, and finally, a small number of producers apply 225 kg ha^{-1} of fertilizer which represents 11.5%. The yield of maize was around 6443.3 kg ha^{-1} in the region, it was observed that the partial factor productivity of nitrogen remains low as compared with the optimal N management, the value was 20.4 kg kg^{-1}, and the rates of cost fertilizer was 125￥ 50 kg $^{-1}$. We can conclude that the low cost of N and less knowledge of fertilizer management is the motivation for excessive utilization. However, regular training of producers can help adopt good practices of optimal N management, minimize environmental risks, and can save money, and reduce the cost of production.

Key Words: Fertilizer, maize production, nitrogen management, partial factor productivity

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1. Introduction

The increase in world population intensified the use of chemical fertilizer for the production of various foods with a higher focus on cereals crops (Ladha et al., 2005). It was reported that about 80% of farmers depend on inorganic nitrogen (N) fertilizer. The increase in food production in the past few decades is due to the overuse of agricultural inputs particularly chemical N fertilizer (Fao, 2008). It was elucidated that cereals consume nearly half (49.3%) of the total world fertilizers; specifically, maize (16.2%), wheat (15.3%), and rice (13.7%), and the remaining cereals consume 4% of the world fertilizer (Ladha et al., 2005). Also, a global N-use was reportedly increased by 20-folds.

Nitrogen is one of the most important yield-limiting nutrients in crop production that is highly mobile and easily soluble. It is required in comparatively higher amounts than any other soil nutrients. It is essential for the growth and development of the plant and it acts as a building block for protein (Zhang et al., 2012). Effective management of nitrogen in the soil-plant system is challenging due to its mobile nature and propensity for loss. The North China Plain (NCP) is one of the intensive production areas with the dominant production system of winter wheat and summer maize (Chen et al., 2010). It is obvious that nutrient mismanagement is one of the most important challenges that result in several agronomic and environmental challenges. Although the dynamics of N are influenced by various factors, and there is no response as positive as in the cultivation of maize and wheat in summer or winter, associated with several factors that have to do with proper management and the application of this element during an appropriate period that the plant needs for its development (Bortolotto et al., 2012). In recent years, the application of N has been increasingly high in the North China Plain

(Zhang et al., 2011). The reason for the overapplication of N fertilizer in this belt is related to the low cost of fertilizer, easy availability, and farmers' perceptions of 'high N inputs for higher maize yield'. Overuse of N fertilizer may enhance grain yield up to a specific level, but the yield increase starts declining after that threshold level, which then contributed to several environmental effects such as soil degradation, eutrophication, and others.

The N fertilizer is one of the expensive inputs, costing more than $45 billion a year (Ladha et al., 2005). Moreover, its use in maize production varies depending on economic development. For example, the N use in China is profoundly higher than that of the world average. On contrary, the N use in Africa and other least developed countries is extremely low. In Africa, the average fertilizer use seldomly exceeds 20 kg ha^{-1}, which is the major responsible challenge for lower per capita food production and the high prevalence of food insecurity. Whatsoever, overapplication, inadequate use, and misuse affect crop production and soil productivity. Therefore, fertilizer management (particularly N) is one of the important strategies for smallholders to enhance crop productivity and tackle environmental degradation (Yan et al., 2016).

Several studies revealed that optimized use of N fertilizer enhances crop production and improves NUE; but it has started to decline in the last few years in this region (Chen et al., 2008). Adoption of optimized N application among farmers in this region reduces the amount of N application, which then helps to reduce the acquisition costs of inputs and decreases the production cost, to improve the profitability, enhance grain yield and minimize environmental pollution (Sui et al., 2013). Several studies have been conducted to increase maize yield and N efficiency, which have already been performed in the same region with the use of optimal N above 300 kg ha^{-1}. This amount of fertilizer applied by the producers remains high. There is a gap in production costs due to the high N application. Due to this, we try to build rational N applications to increase maize yield and N use efficiency. Therefore, the present survey study was conducted to investigate the fertilizer consumption trends (particularly N) and their effects on grain yield and nitrogen use efficiency in Quzhou county of the NCP.

2. Methodology

2.1. Site Description

The field survey was conducted in Wang Zhuang, Xing yuan, and Sitton villages in Quzhou county of Hebei province, China. The area is located at the latitude and longitude of 36.87°N and 115.02°E. The study area is located in a temperate monsoon climate with an average annual temperature of 13.2 °C. The accumulated annual precipitation ranges from 213-840mm with a mean of 494 mm. About 68% of regular annual rainfall was in between June and September (Gao et al., 2014). The total population and total arable land of the study area are about 433,000 and 66,700 hectares, respectively. The per capita arable land is about 0.15 ha while the per capita net agricultural income among rural households was US$944 in 2008, which is comparatively lower than the urban households of US$2,290 (Statistics of China, 2015). Quzhou County is one of the most prominent hubs of Science and Technology Backyards of China Agricultural University in which new agricultural technologies developed and demonstrated. In this region, a summer maize *(Zea mays* L.*)* and winter wheat *(Triticum aestivum* L.*)* rotation is the dominant cropping system ((Lawal et al., 2022).

2.2. Sampling procedure and sampling size

In this study, the non-probability sampling method was used for convenience. Through this technique, respondents were chosen depending on their availability or other criteria which were considered representative by the researcher (Brondani et al, 2000). According to Dias, et al, (2009), convenience sampling helps to obtain responses from people who are available and willing to participate. The selection of respondents followed the method of random sampling. The participant householders were selected by communicating with community leaders. A total of 61 maize producers were selected for the survey based on the aforementioned criteria. In this study, three villages (Wang Zhuang, Xing yuan, and Sitton) were selected based on their potential for maize production and overuse of fertilizer. Both open and close-ended questionaries were prepared that help to collect the major variables influencing maize production and fertilizer use efficiency. The survey study was undertaken in these three villages in August 2020. Before the start of the survey, the questionnaires were translated into Chinese, and the data was collected by the enumerators who know the culture and speak the same language.

During the interview, the respondent's answers were recorded on each printed question sheet. The major information collected was the type of fertilizer used, amount of fertilizers used, maize yield obtained**,** time of fertilizer application (and at what plant growth stages were applied), fertilizer cost, areas allocated for maize plantation, and so on.

2.3. Data collection

In the present study, both primary and secondary data were collected. The primary data were collected through pre-tested and semi-structured questionnaires. The questionnaires were designed in a way that enables the collection of relevant information capable of answering the research objectives. The secondary data were collected from different published sources and reports.

2.4. Statistical analysis

The data were analyzed using descriptive statistics such as mean and frequency distribution to show the socio-economic characteristics of the respondents and other variables. The nitrogen use efficiency component (PFPN) was calculated in excel by following the standard formula as indicated below in eq (1) as reported in (Wang et al., 2017). Pearson correlation was conducted to reveal the magnitude and direction of different variables among each other. Data were subjected to SPSS Version 26. All the illustrations were conducted by using Sigma Plot version 12.5.

$$PFPN = \text{Grain yield}/\text{N application amount} \quad (1)$$

3. Results and discussion

3.1. Socio-economic characteristics of the sample respondents

Among the sampled respondents, about 36% were male-headed households and 64% were women-headed households (Fig 1). Education is one of the most important tools influencing the farmer's decision in crop production. It was assumed that the one with better education has a better probability of adopting modern agricultural technologies than uneducated farmers. In this study, the educational status showed that about 8.3% of the sampled respondents do not have a formal education, 11.6% have a formal education, 21.6% have a medium-level education, and 58.3% of the sampled respondents have a high school and above (Fig 1). In line with these findings, Lu et al., (2015a) reported that farmers of all ages and different levels of education adopted good practices in the cultivation and management of fertilizers in order to increase their production and reduce environmental risks. However, the constant training of farmers can boost incomes, and improve their lives and the rural economy.

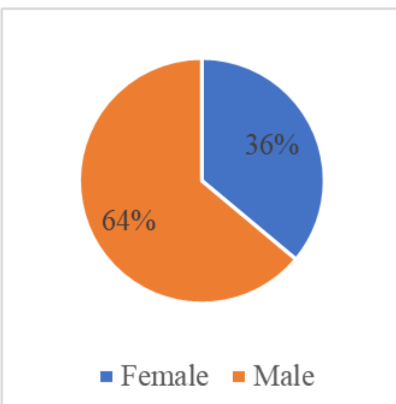

Figure 1: Gender of respondents

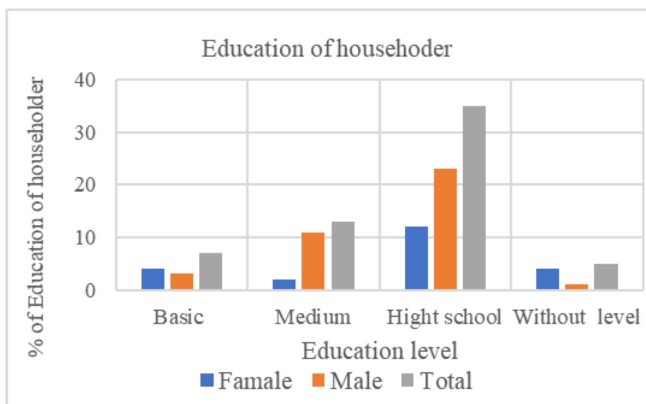

Figure 2: Education of householder

3.2. Fertilizer use trends in the study area (type and rate)

According to the interviewees in the region, most farmers use N by 40%, then phosphorus is the second usual fertilizer at 25% and the third is the compound fertilizer NPK, the least used fertilizers in the region are potassium and organic fertilizers such as straw and vegetable remains, ilustread in Fig 3. Our study corroborated that obtained by Okumura et al.,(2013), which pointed out the importance of N being the primary macronutrient most required by maize, for this reason, most of the time it is the one that limited the grain productivity. Our studies corroborated those obtained by Jin et al.,(2012) carried out a long experiment which illustrated that the compound compost fertilizer like N, P, and K fertilizers could sustain soil yields and productivity. However, the understanding of the farmers in this region, combined use of these elements can increase production and overcome the needs of the crop in all stages of the crop. Although, it can be noted that the excessive use of these fertilizers as reaffirmed may be susceptible to environmental risks and soil degradation. K is the third important mineral for crops development and fecundity, our results coincided reported by Cui et al., (2008), which conducted a survey in three years in NCP, and found that 35% and 52% of small farmers who do not apply well fertilizer (K) on maize and wheat fields (Zhan et al., 2016). Another research conducted in the same region revealed that the use of K fertilizer is a little lower compared with N fertilizer and even lower than that of P (Wu et al., 2013). Therefore, our results consolidated with those described by these authors, that N is a nutrient demanded much by crops. It is possible that for the achievement of yields through the application of K it is essential to make a strategy of rational management of this element according to the necessity and availability of the K in the soil.

The application of organic fertilizers (manure) is much lower in this region, however, our results coincided with those found by Lu et al., (2015b), that in two consecutive years, the application of organic fertilizers did not increase the number of stalks compared with manure-free, although there was a slight increase in grain. In fact, this showed the greatest fear that producers in the application of manure in this region, in addition to other studies which showed some difficulties in acquiring this fertilizer. In this, the use of fertilizers N, P, K, and manures, the rates should be obtained by agronomic suggestions after determining the level of soil fertility in each field conditions (Meng et al., 2013).

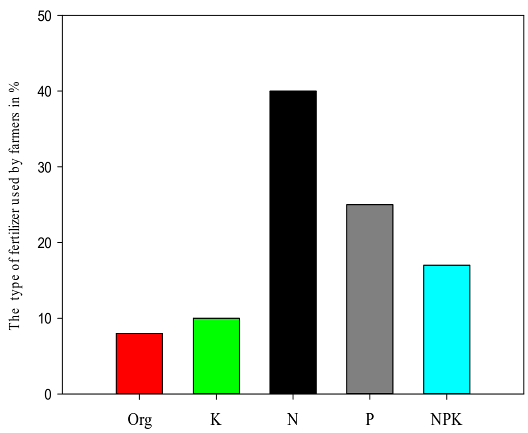

Figure 3 The type of fertilizers used by farmers

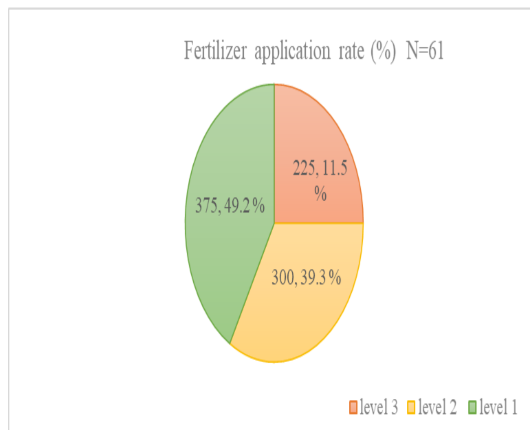

Figure 4 Fertilizer application rate

According to the producers interviewed in the region, there is excessive use of fertilizer that contributed to the risk to the environment and the soil degradation. Although, there is some contribution to maize yield in the region. In the present study, this data is similar to that found by some authors who carried out a similar study that illustrated the excessive use of fertilizers. Thus, most producers apply the fertilizer that varies from 375 kg ha^{-1} which represented 49.2%, followed by 300 kg ha^{-1} which represented 39.3%, and finally, a small number of growers apply 225 kg ha^{-1} fertilizer which represented 11.5%, respectively (Fig 4). Farmers interviewed in the region, reported that the rate of fertilizers they apply is sometimes discussed with other farmers, and decide to apply a certain dose or amount of fertilizer to boost crop yields, especially maize. In the farmers' opinion, a higher dosage of fertilizer will boost yields. Other farmers pointed out that they have inherited and/or this amount to be applied from their parents who teach them in-field activities. The farmers are unanimous in stating that they apply fertilizers in their field of impulsive cultivation and the production and productivity in the yield of maize. Although the practice of using excessive doses of fertilizer is common in the region, they do not care about the adverse environmental consequences, they are only concerned with increasing income and covering their expenses to the detriment of production.

N is a very important element in the whole growth stages of the plant, especially for maize, the farmers of this region used it in large proportions, however, the farmers' understanding of excessive use of N can influence the yield of corn. Thus, the rates of N applied to exceed those recommended by extensionists or researchers. Our results corroborated that described by Li et al., (2020), illustrated that most Chinese farmers try to achieve high peak numbers through the high application of seeding rates and much inputs of N fertilizer. We observed that the excess of N applications does not promote the yield of maize compared with optimal N. A study carries out by Meng et al., (2013), showed that small farmers in the NCP region, only 37% of farmers applied a reasonable amount of N, while 32% and 31% apply too much and too little. These results found by these authors corroborated those obtained in this research. The majority of Chinese farmers apply large quantities of chemical fertilizers, as it is also noted that yields remain very low (Pan et al., 2017). However, there is a need for producers to adopt good practices in the management and proper management of N to reduce environmental risks and mimic production costs. Our results corroborated with those obtained by (Lu et al., 2015b).

3.4. Grain yield, partial factor productivity and fertilizer cost

According to the study, it was found that the amount of fertilizer applied by the producers has been very high, 325 kg ha^{-1} on average, as compared with the amounts recommended by the researchers, in such circumstances, the degradation of the environment has been noted. The production of maize in the region was 6443.3 kg ha^{-1} according to the study, it was observed that PFPN remains low as compared with optimal N management, whose average was 20.4 kg kg^{-1}, and the rates of fertilizer acquisition was 125 ￥ 50 kg $^{-1}$. Table 1 shows the N rate, grain yield, PFPN, and fertilizer cost. In previous studies conducted by Wang et al., (2019), in a survey obtained on average wheat grains, the yield ranged from 3.4 kg ha^{-1} to 8.3 kg ha^{-1} corresponding to the average application rate of N of 284 kg ha^{-1}.

Our results converged with those obtained by Zhang et al., (2011), which due to the excess of N applied obtained a PFPN around 20 kg kg^{-1} differed from those obtained by Zhao et al., (2016) those are having conducted a survey in the same region and other field trials obtained a PFPN ranging from 50 to 60 kg kg^{-1} respectively. However, this showed a need to adopt farmers to adhere to the use of optimized N, according to our study conducted in the same region, which also showed an increase in maize yield. Therefore, most of the small farmers continued to agree that higher levels of fertilizers and elevated grain yields are synonymous (Yan et al., 2016). However, higher farm incomes and lower prices of N fertilizers, are encouraging farmers to intensively increase the use of the high rate of N in the NCP (Yan et al., 2018). It is noted that in small-scale agriculture in NCP, less knowledge about crop responses to N fertilizer and an optimal N rate often resulted in excess or sub-application of N fertilizer (Li et al., 2020). Therefore, there is a need to support it in adopting more technical knowledge to adhere to the use of optimal N, in order to increase production and productivity and reduce environmental risks. Although in the same region it has been observed that small producers have benefited from several trainings and rural extension services, teams of researchers and students allocated in each village that is to support farmers in concrete solutions to mitigate the problems.

Table 1 N rate, grain yield, PFPN and fertilizer cost of fertilizer

Sample n= (61)	N rate (kg ha^{-1})	Grain yield (kg ha^{-1})	PFPN (kg kg^{-1})	Fertilizer (50 kg￥$^{-1}$)	%
6	375	5250	14.0	125	9.8
12	300	5700	19.0	150	20.0
8	375	6000	16.0	100	13.0
5	225	6200	27.5	120	8.2
11	375	6750	18.0	110	18.0
3	375	7200	19.2	100	5.0
12	300	7500	25.0	120	19.6
2	375	7800	20.8	130	3.2
2	225	7250	24.4	170	3.2
Average	325.7±49.12	6443.3±880.3	20.4±4.15	125±22.9	100%

3.5. Person correlation coefficient between variables

The results indicated a very strong correlation between the farmer's age and production, the older the farmer's age the greater the production, it can be assumed that the factor determined the experiences that these farmers have throughout their life. Another important factor is the hereditary knowledge they learn over the course of their lives from their parents and grandparents who teach some rudimentary techniques that help them to increase production and productivity, the handling of land cultivation and cultural tracts, etc. Another aspect that needs to be noted is that farmers participate in various training at the experimental center in Quzhou, so they improve certain techniques in a way that drives production and productivity in the region. On the other hand, the costs of fertilizer do not have a positive correlation with production. It was found that the applied quantities of fertilizers have a positive correlation, and it showed that fertilizers played a very fundamental role in the increase of maize production to small producers in this region of NCP. It was also observed that the price of maize applied by farmers has a positive correlation with the amount of maize that was harvested per hectare in the region. Our results were different from those obtained by Qian et al., (2016) and had carried out Survey in the NCP which culminated in fieldwork in the same region, do not observe any correlation between the N rate and yield of the crop, illustrated excessive use and improper N application as common practice in maize production. We also observed that the price of maize applied by farmers has a positive correlation with the amount of maize harvested per hectare in the region, indeed, this fact could be explained that, the price promoted the income beyond the existence of potential buyers, table 2 show that the correlation of person between the variables. However, the rates and levels of N applied naturally rely on the ratio between the price of fertilizer N and maize grain (Lu et al., 2014). However, Wu et al., (2014) reported that the benefits can be improved through the application of other better fertilizer management strategies and regular training of local producers. The costs of acquiring fertilizer do not have a positive correlation with production. It was found that the applied quantities of fertilizers have a positive correlation, it showed that fertilizers played a very fundamental role in increasing the production of maize for small producers in this region of NCP.

Table 2. The Person correlation of age householder, cost of fertilizer, amount of fertilizer, harvest maize kg ha $^{-1}$, price of maize, total of amount harvested and maize planted per hectare.

Variable	Age of Householder	Cost of fertilizer in 50 kg ￥$^{-1}$	Amount of fertilizer	Harvest maize per kg ha^{-1}	Price of maize	Total of amount harvest	Maize planted ha^{-1}
Age of Householder	1	0.021	0.073	-0,126	0,071	0,022	0,576**
Cost of fertilizer in 50 kg ￥$^{-1}$	0,021	1	-0,114	0,130	0,071	-0,121	0,070
Amount of fertilizer	0,073	-0,114	1	-0,198	0,086	0,330**	-0,103
Harvest maize per Kg ha $^{-1}$	-0,126	0,130	-0,198	1	0,082	-0,083	0,257*
Price of maize	0,132	0,071	-0,086	0,552	1	-0,070	0,566**
Total of amount harvest	0,022	-0,121	0,330**	-0,083	-0,070	1	-0,057
Maize planted ha^{-1}	0,576**	0,070	-0,103	0,257*	0,566**	-0,057	1

The correlation between parameters was determined by the Pearson Correlation test. ** $P < 0.01$, * $P < 0.05$

4. Conclusion and Suggestion

Maize is the largest crop cultivated in NCP, followed by wheat, and the agroecological conditions of the region allowed farmers to adopt a crop rotation production system that consisted of sowing maize in summer and wheat in winter. Farmers applied a high level of fertilizers, especially N, such as 375 kg ha $^{-1}$ (49.2%), 300 kg ha $^{-1}$ (39.3%), and 225 kg ha $^{-1}$ (11.5 %) respectively. The maize yield was 6443.3 kg ha^{-1} this amount still is low compared to the yields obtained through the optimal application of N in this region. The PFPN was about 20.4 kg kg^{-1} and the average fertilizer cost was 125￥ 50 kg^{-1}. Most farmers apply the fertilizer twice at the base planting and V6 and don't observe the nutritional requirements in which the plant needs it to increase the productivity of the crop. Further, the low price of N and less knowledge of fertilizer management motivate farmers to excessive use of fertilizer, and this contributes negatively to environmental safety, such as soil degradation, water, and environmental pollution. Generally, to produce maize in a sustainable manner, farmers should use the optimized N management practice, and to strengthen this, regular training for farmers can help them adopt good agronomic practices which boost maize production, save money and reduce environmental pollution.

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