Effects of formulated fertilizer, irrigation and varieties on wheat yield in Shaanxi China

Xiaoying Wang¹, Yanan Tong¹,²*, Pengcheng Gao¹, Fen Liu¹, Yimin Gao¹, Zuoping Zhao¹ and Yan Pang¹

¹College of Resources and Environment, Northwest A&F University, Yangling, Shaanxi, China
²Key Laboratory of Plant Nutrition and Agricultural Environment in Northwest, Ministry of Agriculture, Yangling, Shaanxi, China

ABSTRACT

In order to study the effects of formulated fertilization, irrigation and different varieties on crop yields and farmer’s income, this research used household survey data and demonstration test data of formulated fertilization, which was collected from the project of soil testing and formulated fertilization in Shaanxi province from 2007 to 2011. For analysis, there were a total of 53 counties in the sample. The results show that in Weibei, Guanzhong and Qin-Ba regions, compared with conventional fertilization, formulated fertilization decreased nitrogen (N) fertilizer rates by 31.92%, 12.59% and 10.13% respectively, decreased phosphate (P₂O₅) fertilizer rates by 20.44%, 2.10% and 26.19% respectively, increased potassium (K₂O) fertilizer rates by 105.98%, 193.99% and 382.58% respectively. The yields of wheat improved 330 kg ha⁻¹, 403 kg ha⁻¹ and 738 kg ha⁻¹, the yield increase rates were 7.73%, 6.26% and 19.71%, the average profits increased about 906 yuan ha⁻¹, 689 yuan ha⁻¹ and 1423 yuan ha⁻¹ respectively in the three regions. In addition, the average yields were higher up to 19.07%, 14.96% and 17.76% respectively when irrigation had been used than without, and it was not the most productive varieties that were the most grown in the three regions. Therefore, the focus of the wheat production in the future must pay more attention to the formulated fertilizer application, conduct rational irrigation and encourage the use of more productive varieties, to provide effective protection for the province and to enhance national food security.

Key words: Formulated fertilizer; Increasing production and income; Irrigation; Varieties; Wheat; China

INTRODUCTION

With an increase of population and a decrease of arable land, the contradiction in China between food security and resource consumption and environmental protection is becoming more and more severe[1]. From 1980 to 2011, the total annual grain production increased by 78.19% and inorganic fertilizer application increased by 349.36% in the country. However, the crop-sown area decreased by 5.68% over the same period[2]. The basis of solving the food security pressure is through increasing grain production, which is decided by the food-crop planting area and the per unit area yield of grain. But due to the limitation of arable land, the increase of the grain production can only rely on the improvement of yield[3]. The overuse of inorganic fertilizer, especially synthetic nitrogen fertilizer, in agricultural systems during the last few decades has caused serious consequences in many areas of China[4-8], and it has raised a series of environmental problems[9-11], including nitrate pollution of groundwater, eutrophication of surface water, greenhouse gas emission and other forms of air pollution, acid rain, soil acidification. It has been reported that average soil pH has declined 0.5 units due to the overuse of N fertilizer in the past two decades in China[12]. So how to improve crop yield and reduce environmental risk is an urgent issue which needs to be solve, especially with respects to China.

Fertilization, irrigation and crop varieties are important factors to maintain soil fertility and increase crop
yields[13-16]. In addition, wheat is one of the most important food crops throughout the world - the yield and planting area accounts for about a third of the world’s food[17]. China is the world's largest production, consumer and importer of wheat, and the development of wheat production has a great significance to the country's food security. Meanwhile, Shaanxi province is one of the major areas of wheat production on a national scale. From a report published by the United Nations, soil testing and formulated fertilization technology is recognized as an environmentally friendly technique[18], and has also been energetically popularized in China in recent years[19].

Thus, our objective of this study was to understand the effects of formulated fertilizer, irrigation and varieties on wheat yield and farmer’s income; with the aim to provide the basis for food security measures of the province and the nation.

**EXPERIMENTAL SECTION**

**Study area**

Shaanxi province is located in the middle reaches of the Yellow River and the upper reaches of the Yangtze River of the eastern part of northwest China, and it falls between latitudes 31°42’ and 39°35’N, and longitudes 105°29’ and 111°15’E. The area is 2.058×10^5 km² and about 880 km from north to south and 160 to 490 km from east to west. The whole province from north to south can be divided into four agro-ecological zones, which are: Loess plateau area of northern Shaanxi, Weibei dry plateau, Guanzhong irrigated area and Qin-Ba mountain area of southern Shaanxi, and in this study abbreviated to North, Weibei, Guanzhong and Qin-Ba respectively. Winter wheat is planted in the last three regions, which is the study area. Main soil types, climatic conditions and soil properties in the different regions are shown in Table 1.

<table>
<thead>
<tr>
<th>Region</th>
<th>Main soil types</th>
<th>Weibei</th>
<th>Guanzhong</th>
<th>Qin-Ba</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Black loess soils,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Loess soils</td>
<td>9~13</td>
<td>10~14</td>
<td>11~16</td>
</tr>
<tr>
<td></td>
<td>Cinnamon soils</td>
<td>530~630</td>
<td>600~720</td>
<td>670~1270</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>7.9 ± 0.4</td>
<td>7.9 ± 0.3</td>
<td>6.8 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>Organic matter (g kg⁻¹)</td>
<td>12.8 ± 4.4</td>
<td>15.3 ± 7.0</td>
<td>20.6 ± 7.9</td>
</tr>
<tr>
<td></td>
<td>Alkali-hydrolysable N (mg kg⁻¹)</td>
<td>63.3 ± 22.7</td>
<td>67.6 ± 27.0</td>
<td>115.0 ± 49.3</td>
</tr>
<tr>
<td></td>
<td>Available P (mg kg⁻¹)</td>
<td>14.8 ± 11.4</td>
<td>25.9 ± 12.5</td>
<td>18.1 ± 16.9</td>
</tr>
<tr>
<td></td>
<td>Available K (mg kg⁻¹)</td>
<td>160.3 ± 50.9</td>
<td>165.0 ± 60.7</td>
<td>116.6 ± 46.4</td>
</tr>
</tbody>
</table>

Data sources: Soil types and climate[20]; Soil chemical properties: data collected by testing centers in the different regions. Unpublished.

**Table 2 Distribution of the sites and number of samples investigated and experimented in the study**

<table>
<thead>
<tr>
<th>Region</th>
<th>Counties</th>
<th>No. of conventional fertilization samples</th>
<th>No. of formulated fertilization samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weibei</td>
<td>Baoji county, Bin county, Changwu county, Chengcheng county, Chunhua county, Fuping county, Hancheng city, Heyang county, Linyou county, Long county, Pucheng county, Quanqiang county, Xianyi county, Yaozhou area, Yijun county, Yongshou county Bagiao area, Changan area, Chencang area, Dali county, Fengxiang county, Fufeng county, Gaoling county, Hu county, Hua county, Jintai area, Jingyang county, Liqun county, Ba mountain area of southern Shaanxi</td>
<td>7348</td>
<td>320</td>
</tr>
<tr>
<td>Guanzhong</td>
<td>Lanwei area, Mei county, Qishan county, Qian county, Qinou area, Sanyuan county, Tongguan county, Weinbo area, Weicheng area, Wugong county, Xingping city, Yulin area, Yangling area</td>
<td>11416</td>
<td>350</td>
</tr>
<tr>
<td>Qin-Ba</td>
<td>Nanzheng county, Shanyang county, Shangzhou area, Xixiang county, Xunyang county, Yangling area</td>
<td>2992</td>
<td>100</td>
</tr>
</tbody>
</table>

Data sources:

Data used in this analysis was collected from 53 counties from household’s conventional fertilization and demonstration trials on formulated fertilization, taken from the project “soil testing and formulated fertilization in Shaanxi province during the years 2007 to 2011”. Where, household’s conventional fertilization was surveyed by the staff at the Chinese National Soil Testing Stations in Shaanxi province every year, the information from the survey used for this research included: crop varieties, crop yield, fertilizer types, fertilizer rates, and fertilizer application time. At last, the effective survey number was 21756. Demonstration trials were conducted by the staff on representative households’ plots every year. The amount of formulated fertilization according to the local situation, and other field managements, were employed using the standard farming practices. At last, the experimental sample size was 770. The distribution of the sites and number of samples investigated and experimented in the different regions are shown in Table 2.
regions is shown in Table 2.

Statistics
Data was analyzed by EXCEL and SPSS16.0 software. In this study, the calculation method of indexes are as follows:

Yield increase rate, \(\% = \frac{\text{Yield of conventional fertilization} - \text{Yield of formulated fertilization}}{\text{Yield of conventional fertilization}} \times 100\)

Increased profit, yuan ha\(^{-1}\) = (Production value of formulated fertilization – Costs of formulated fertilization) – (Production value of conventional fertilization – Costs of conventional fertilization)

RESULTS

The nutrient inputs on wheat between conventional and formulated fertilization
The inorganic inputs for wheat were different between conventional and formulated fertilization (Table 3). For the whole province, the average inorganic N, P\(_2\)O\(_5\), and K\(_2\)O inputs were 183, 110 and 21 kg ha\(^{-1}\) respectively under conventional fertilization, while were 146, 96 and 56 kg ha\(^{-1}\) respectively under formulated fertilization, which indicated that formulated fertilization had the effect of “decreasing N”, “decreasing P” and “increasing K”. The laws of it in the three regions were consistent with the whole province. In Weibei, Guanzhong and Qin-Ba regions compared with conventional fertilization, formulated fertilization for N decreased by 31.92%, 12.59% and 10.13% respectively, for P\(_2\)O\(_5\) decreased by 20.44%, 2.10% and 26.19% respectively, for K\(_2\)O increased by 105.98%, 193.99% and 382.58% respectively. In addition, in accordance with the sown areas in the three regions[21], we calculated if households applied the amount of fertilizers on the basis of formulated fertilization, then in Weibei, Guanzhong and Qin-Ba regions could save N up to 85900 t, 77200 t, 11300 t respectively during wheat growth every year, with the whole province as 169900 t; meanwhile it can also save P\(_2\)O\(_5\) up to 36900 t, 8000 t and 19900 t respectively, with the whole province as 64800 t.

<table>
<thead>
<tr>
<th>Region</th>
<th>Conventional fertilization</th>
<th>Formulated fertilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P(_2)O(_5)</td>
</tr>
<tr>
<td>Weibei</td>
<td>185±5</td>
<td>112±55</td>
</tr>
<tr>
<td>Guanzhong</td>
<td>195±67</td>
<td>115±69</td>
</tr>
<tr>
<td>Qin-Ba</td>
<td>137±56</td>
<td>84±46</td>
</tr>
<tr>
<td>The whole province</td>
<td>183±74</td>
<td>110±63</td>
</tr>
</tbody>
</table>

The fertilizer costs on wheat between conventional and formulated fertilization
Assuming that using formulated fertilizers will have no effect on pesticides, labour, mechanical power and other important agricultural production factors, under the premise we analyzed formulated fertilization effect on fertilizer input costs for households[19]. In Weibei region, the fertilizer costs averaged 1514 yuan ha\(^{-1}\) under conventional fertilization, while formulated fertilization would reduce this to 246 yuan ha\(^{-1}\), averaging at 1268 yuan ha\(^{-1}\). The situation in Guanzhong and Qin-Ba regions shown that the fertilizer costs of formulated fertilization increased 117 yuan ha\(^{-1}\) and 52 yuan ha\(^{-1}\) respectively, compared with conventional fertilization (Table 4). The reason was that the costs of nitrogen and phosphorus fertilizers both decreased, however the costs of potassium fertilizer increased, which resulted in formulated fertilization not significantly reducing fertilizer input costs.

<table>
<thead>
<tr>
<th>Region</th>
<th>Costs of conventional fertilization</th>
<th>Costs of formulated fertilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P(_2)O(_5)</td>
</tr>
<tr>
<td>Weibei</td>
<td>831</td>
<td>558</td>
</tr>
<tr>
<td>Guanzhong</td>
<td>877</td>
<td>576</td>
</tr>
<tr>
<td>Qin-Ba</td>
<td>615</td>
<td>419</td>
</tr>
<tr>
<td>The whole province</td>
<td>825</td>
<td>548</td>
</tr>
</tbody>
</table>

Note: The price of inorganic fertilizer N, P\(_2\)O\(_5\), and K\(_2\)O are 4.5 yuan kg\(^{-1}\), 5.0 yuan kg\(^{-1}\) and 5.5 yuan kg\(^{-1}\) respectively.

The fertilization benefit on wheat between conventional and formulated fertilization
In Weibei, Guanzhong and Qin-Ba regions the yields of wheat were 4269 kg ha\(^{-1}\), 6437 kg ha\(^{-1}\) and 3742 kg ha\(^{-1}\) respectively under conventional fertilization, compared with it the increased yields were 330 kg ha\(^{-1}\), 403 kg ha\(^{-1}\) and 738 kg ha\(^{-1}\) respectively, the yield increase rates were 7.73%, 6.26% and 19.71% respectively, and the increased profits were up to 906 yuan ha\(^{-1}\), 689 yuan ha\(^{-1}\) and 1423 yuan ha\(^{-1}\) respectively under formulated fertilization (Table
Although yield increase rate reached up to 19.07%, 14.96% and 10.76% in the three most productive varieties were Xinong 928, Xinluo 11 and Shanmai 75, respectively, compared with conventional fertilization. This indicated a potential of increased yields if the households were encouraged to use the more productive varieties.

Effect of irrigation on wheat yield
In general, the environment in northwest China belongs to arid and semi-arid regions, therefore any agricultural activity is highly dependent on irrigation[22]. In Weibei, Guanzhong and Qin-Ba regions, the average yields were significantly higher when irrigation had been used than without, and the yield increase rates up to 19.07%, 14.96% and 17.76% respectively under irrigation (Table 6). It indicated that irrigation had potential to increase wheat yields.

Effect of wheat varieties on yield
Apart from using formulated fertilizers and reasonable irrigation, wheat varieties also had a significant impact on the yield. In this study, households used a total of more than 100 varieties. We made statistics on the top 10 varieties in each region and calculated their average yields (Table 7). In Weibei, the yield varied from 3571 to 5320 kg ha\(^{-1}\) and the most productive varieties were Xiaoyan 22, 90 and Changwu 134. In Guanzhong the yield varied from 5763 to 7451 kg ha\(^{-1}\) and the three most productive varieties were Yanmai 8911, Xinong 2611 and Zhengmai 9023. In Qin-Ba the yield varied from 2992 to 4524 kg ha\(^{-1}\) and the three most productive varieties were Xing 9418, Mianyang 33 and Chuanmai 30. It was interesting to note that it was not the most productive varieties that were the most grown. This indicated a potential of increased yields if the households were encouraged to use the more productive varieties.

DISCUSSION

Excessive inorganic fertilization not only wasted resources but also led to many serious environmental problems[11,23-24]. Hence, in order to change the situation of excessive fertilization as soon as possible, it is encouraged and recommended households decrease the fertilizer application rate, especially with nitrogen and phosphorus.
phosphorus fertilizers. This is because the lower fertilization rate does not necessarily mean the reduction of yield[25]. For example, a great number of research in rice/wheat rotation systems and winter wheat/summer maize rotation systems has identified that reducing the current N application rates by 30% to 60% could increase N fertilizer efficiency, whilst still maintain crop yields and substantially reduce N losses to the environment[11,26]. Lou et al[27] found that on the basis of households conventional fertilization, reducing N fertilizer by 20% could increase crop yield and quality. Meantime, the research for this paper showed that in Weibei, Guanzhong and Qin-Ba regions compared with conventional fertilization, formulated fertilization for N decreased by 31.92%, 12.59% and 10.13% respectively, for P2O5 decreased by 20.44%, 2.10% and 26.19% respectively, while the yield increase rates were 7.73%, 6.26% and 19.71% respectively, and the increased profits were up to 906 yuan ha−1, 689 yuan ha−1 and 1423 yuan ha−1 respectively. If households used the amount of fertilizers according to formulated fertilization, Shaanxi province could save N 169900 t and P2O5 64800 t each year during wheat growing. Zhang[28] reported that every ton of nitrogen fertilizer from production and from fertilizer transportation to farmlands, emitted an equivalent CO2 up to 12.85 tons in China. Based on that, we calculated the amount of reducing CO2 emissions was 2.183 million tons from the reduction in nitrogen fertilizer use on wheat on the whole province each year.

“Fertilizer is strength, water is life”, reasonable fertilizer and water management is very important factor that affects crop yields, and appropriate levels of irrigation can promote crops growth and development[29-31]. Fei et al[32] found that irrigation quantity had a significant positive effect on increasing wheat yield. Zhang et al[33] also reported that with appropriately increasing irrigation amount, wheat yield can also increase accordingly. The research in this paper showed that in Weibei, Guanzhong and Qin-Ba regions the yield increase rates were 19.07%, 14.96% and 17.76% respectively under irrigation than without. All in all, balanced fertilization and rational irrigation is the key to obtain a high and stable yield and to reduce the environmental risks of dual protection[34-36].

In addition, we also found that it was not the most productive varieties that were the most grown. The high-yielding varieties had more biomass and were more sensitive to the nutrient inputs than the low-yielding varieties, besides high-yielding varieties with high nitrogen and phosphorus fertilizer use efficiency, nitrogen and phosphorus fertilizer agronomy efficiency, nitrogen and phosphorus fertilizer physiological efficiency and nitrogen and phosphorus fertilizer partial factor productivity[37-39]. Ye et al[40] also reported that variety was vital to obtain wheat high yield and super high yield. But nationwide, the proportion of high-yielding and super-high-yielding wheat cultivation was still small, so improving the level of wheat yield, expanding high-yielding and super-high-yielding cultivated area is an important approach to increase the wheat production in the future in China.

CONCLUSION

In Weibei, Guanzhong and Qin-Ba regions compared with conventional fertilization, formulated fertilization for N decreased by 31.92%, 12.59% and 10.13% respectively, for P2O5 decreased by 20.44%, 2.10% and 26.19% respectively, for K2O increased by 105.98%, 193.99% and 382.58% respectively; the increased yields were 330 kg ha−1, 403 kg ha−1 and 738 kg ha−1 respectively, the yield increase rates were 7.73%, 6.26% and 19.71% respectively, and the increased profits were up to 906 yuan ha−1, 689 yuan ha−1 and 1423 yuan ha−1 respectively; the yield increase rates were 19.07%, 14.96% and 17.76% respectively under irrigation than without; it was not the most productive varieties that were the most grown. Therefore, the focus of the wheat production in the future must pay more attention to the formulated fertilizer application, along with conducting rational irrigation and encouraging the use of more productive varieties. Therefore, the recommendations identified from this report will help to provide effective protection for food security for the province of Shaanxi and the nation.

Acknowledgment

We thank the Special Fund for Agro-scientific Research in the Public Interest of China (201103003) and the Soil Quality Foundation of China (2012BAD05B03) for their financial support.

REFERENCES