Influence of Different Fertilization Levels on Maize Yield and Fertilizer Effect Based on the "3414" Experimental Design Scheme

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Abstract In order to provide scientific basis for rational fertilization of maize under different soil quality and fertility, the effect of combined application of NPK on yield and fertilizer effect of different maize varieties was studied by using "3414" experimental design scheme in this paper. The results showed that there were significant differences in ear length, ear diameter, barren ear tip length, kernel number per spike, kernel weight and yield among different fertilization treatments. Fertilization can improve the agronomic characters of maize and increase the yield. The yield increase of maize in two experimental plots (MHQ and HZY) was 11.0% – 64.3% and 0.2% – 61.9%, respectively. There was obvious interaction effect among nitrogen, phosphorus and potassium fertilizers, the yield of maize was the highest at the level of medium nitrogen, medium phosphorus and medium potassium fertilization, and the fertilizer effect was in the order of N > P_2O_5 > K_2O. The results of curve fitting showed that the recommended application rates of N, P_2O_5 and K_2O in MHQ plot were 373.7, 74.8 and 79.9 kg/ha, respectively; the recommended application rates of N, P_2O_5 and K_2O in HZY plot were 419.7, 75 and 75 kg/ha, respectively.

Key words Maize, Rational fertilization, Fertilizer effect, Yield

1 Introduction

Maize is one of the three major food crops in the world, mainly used for food and feed processing. At present, more and more attention has been paid to the use of maize industrial processing, and its energy substitution prospects are also very broad in the future. However, there are large blind spots in maize cultivation by the majority of growers. The planting mode and structure are not reasonable enough, and the planting technology does not meet the requirements. The thinking of small farmers leads to growers only cultivating land, not maintaining land, they generally apply more nitrogen fertilizers, less or no phosphorus and potassium fertilizers and medium trace element fertilizers. In terms of organic material input, growers also follow the original model of straw burning and returning it to the field. Therefore, the yield can not be increased, the application of chemical fertilizer and the single variety structure lead to the high incidence of crop diseases and pests, the low yield and quality of maize, and the continuous deterioration of soil structure, which seriously affects the quality of soil and environment[1-2]. It is of great significance to determine the rational application rate and proportion of nitrogen, phosphorus and potassium in maize by testing soil for formulated fertilization.

According to the characteristics of crop fertilizer requirement, soil fertilizer supply performance and fertilizer effect, the "3414" experiment is to put forward the reasonable application rate and proportion of nitrogen, phosphorus and potassium on the premise of measuring soil nutrient status. It is the main field experiment scheme of recommended fertilization for field crops at present. The experimental design scheme is the main field test scheme recommended by testing soil for formulated fertilization, which is widely carried out in the whole country. Fertilization index systems have been established on rice[3], wheat[4], rape[5] and barley[6], respectively. Maize, as the main food crop and new energy alternative crop in China, has received extensive attention[1,7-9], but there are few studies on the recommended fertilization of maize under different varieties, different soil quality and fertility. Therefore, two maize varieties were selected and three different fertilizer ratios of nitrogen, phosphorus and potassium were designed by "3414" scheme to carry out field experiments on different soil quality and establish fertilizer effect model to study the effect of nitrogen, phosphorus and potassium ratio on maize yield, in order to provide a scientific basis for rational fertilization of maize under different soil quality and fertility.

2 Materials and methods

2.1 Materials

2.1.1 Maize tested. The varieties are Huidan 4 and Changcheng 799, provided by Lijiang Agricultural Technology Extension Station.

2.1.2 Fertilizers tested. Nitrogen fertilizer is urea (N 46%), phosphorus fertilizer is ordinary superphosphorus (P_2O_5 14%), potassium fertilizer is potassium sulfate (K_2O 50%). All three fertilizers are provided by Yunnan Yuntianhua Co., Ltd.

2.2 Overview of the experimental site

From June to October 2012, the experiments were carried out in Fengle Village, Lashi Town, Yulong County, Lijiang City, Yunnan Province (26°51′12″

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N, 100°07′01″ E) and Haidong Village, Lashi Township, Yulong County, Lijiang City, Yunnan Province (26°49′08″ N, 100°07′36″ E). The names of two test plots were marked with MHQ and HZY, respectively. This area has a monsoon climate of low latitude warm temperate mountain plateau, it has the three-dimensional climate characteristics of "four seasons in the same mountain, different weather conditions in ten miles". The altitude is 2 459 m, the annual sunshine is 2 475.2 h, the annual average temperature is 14.2℃, and the average rainfall is 897.3 mm. MHQ's soil type is alluvial soil with deep soil layer and sand texture, and there is flat terrain. The previous crop is broad beans. HZY's soil type is red soil with moderate soil texture, and there is no previous crop. Specific soil physical and chemical properties are shown in Table 1.

Table 1 Physical and chemical properties at the 0 – 20 cm deep soil

Plot	pH	OM g/kg	Total N g/kg	Alkail. N mg/kg	Alkail. P mg/kg	Alkail. K mg/kg
MHQ	7.7	38.4	2.10	118.5	16.0	134.0
HZY	5.8	11.6	1.93	76.4	60.0	56.0

2.3 Experimental design The "3414" test scheme was adopted in the experiment, and three experimental factors were set: the application rates of nitrogen fertilizer, phosphorus fertilizer and potassium fertilizer. Each experimental factor had 4 fertilization levels (0, 1, 2, 3), a total of 14 treatments and 3 replicates, with randomized block design. The experimental factors and fertilization levels are shown in Table 2. The plot area was 20 m^2 (3.9 m × 5.1 m). Three ridges of maize were planted in each plot, and the row spacing was 20 cm.

Table 2 Application rate at different fertilizer levels

Levels	N//kg/ha	P_2O_5//kg/ha	K_2O//kg/ha
0	0.0	0.0	0.0
1	180.0	37.5	37.5
2	360.0	75.0	75.0
3	540.0	112.5	112.5

2.4 Test management The MHQ experimental plot was ploughed by machine on April 3, 2012. The farm manure was applied before ploughing at 7 500 kg/ha. On April 4th, the plot was planned according to the design requirements and covered with plastic film. There are 3 rows per plot, large row spacing is 1.2 m, small row spacing is 0.4 m, and plant spacing is 0.35 m. The planting density is 4 050 plants sown in wide-narrow row alternation with two rows for two plants. Seedling emerged on April 15, final singling occurred on April 25, jointing fertilizer was applied on June 18, panicle fertilizer was applied on July 14 at spinning stage, harvest occurred on September 18, and the whole growth period was 163 d. The fertilizer was applied three times, 28% nitrogen fertilizer and all phosphorus and potassium fertilizer were used as base fertilizer. The rest of nitrogen fertilizer was applied as jointing fertilizer (36%) and panicle fertilizer (36%).

The HZY experimental plot was ploughed and leveled by machine on April 6, 2012. Farm manure was applied before ploughing at 7 500 kg/ha. On April 7th, the plot was planned according to the design requirements and covered with plastic film. There are 3 rows per plot, large row spacing is 1.2 m, small row spacing is 0.4 m, plant spacing is 0.35 m. The planting density is 4 050 plants sown in wide-narrow row alternation with two rows for two plants. Seedling emerged on April 18, final singling occurred on April 27, jointing fertilizer was applied on June 21, panicle fertilizer was applied on July 17 at spinning stage, harvest occurred on September 19, and the whole growth period was 165 d. The fertilizer was applied three times, 28% nitrogen fertilizer and all phosphorus and potassium fertilizer were used as base fertilizer. The rest of nitrogen fertilizer was applied as jointing fertilizer (36%) and panicle fertilizer (36%).

The field management of tillage, soil cultivation, weeding and pest control was consistent in all treatments during the growth period of the two experimental plots, and the pest control and weed control were carried out twice in the growth period of maize.

2.5 Data analysis Excel 2010 was used to process and analyze the data, and SPSS 13.0 was used to test the significance of the difference between the two treatments. Univariate quadratic and ternary quadratic equations were used to fit the yield. The optimum model was selected according to the determination coefficients fitted by different equations, and the application rate of nitrogen, phosphorus and potassium fertilizer for the highest yield of maize was determined by the analysis of marginal effect of the model.

3 Results and analysis

3.1 Influence of different treatments on agronomic characters and yield effects of maize

3.1.1 Agronomic characters. It can be seen from Table 3 that compared with no fertilizer treatment ($N_0P_0K_0$), the ear length, ear diameter and kernel number per panicle under fertilization treatment in MHQ plot increased as a whole, but the barren ear tip length of maize decreased significantly, and the kernel weight fluctuated greatly. The ear length, ear diameter, barren ear tip length, kernel number per spike and kernel weight of maize increased significantly under fertilization treatment in HZY plot. Compared with no nitrogen treatment ($N_0P_2K_2$), the ear length of maize under N_1, N_2 and N_3 treatments in MHQ plot increased by 2.9%, 7.9% and 14.3%, respectively. The number of kernels per panicle increased by 21.6%, 25.1% and 17.8%, and the length of barren ear tip decreased by 44.0%, 44.0% and 40.0%. In HZY plot under N_1, N_2 and N_3 treatments, panicle length increased by 10.4%, 11.7% and 2.5%, panicle diameter increased by 23.3%, 32.6% and 9.3%, and kernel number per panicle increased by 34.0%, 33.4% and 34.9%, kernel weight increased by 5.1%, 18.4% and 14.8%, respectively. Compared with no phosphorus treatment ($N_2P_0K_2$), the ear length of maize under P_1, P_2 and P_3 treatments in MHQ plot increased by 13.9%, 10.2% and 5.1%, respectively, and the number of kernels per panicle increased by 44.5%, 50.3% and 48.1%, respectively. The kernel weight increased by 9.2%, 4.2% and 9.2%, respectively, but the barren ear tip length decreased by 44.5%, 50.3%

and 48.1%, respectively. In HZY plot under P_1, P_2 and P_3 treatments, the ear length increased by 11.9%, 8.3% and 18.5%, ear diameter increased by 12.5%, 18.8% and 16.7%, the number of kernels per panicle increased by 16.0%, 15.4% and 18.6%, respectively. The kernel weight increased by 18.5%, 14.1% and 17.6%, respectively, but the barren ear tip length decreased by 66.7%, 33.3% and 66.7%, respectively. Compared with no potassium treatment ($N_2P_2K_0$), the ear length of maize under K_1, K_2 and K_3 treatments in MHQ plot increased by 7.1%, 7.9% and 7.1%, respectively, and the number of kernels per panicle increased by 6.1%, 22.8% and 16.2%, respectively, and the kernel weight increased by 22.4%, 9.2% and 15.2%, respectively. The ear length of maize under K_1, K_2 and K_3 treatments in HZY plot increased by 12.7%, 10.3% and 12.1%, respectively, and the number of kernels per panicle increased by 11.3%, 21.2% and 4.3%, respectively, but the barren ear tip length decreased by 0, 33.3% and 33.3%, respectively.

Table 3 Agronomic characters of maize under different fertilization treatments

Plot	Fertilizer	Treatments	Ear length//cm	Ear diameter//cm	Barren ear tip//cm	Number of kernels per spike	Kernel weight//g
MHQ	N	$N_0P_0K_0$ (CK)	12.6 d	4.6 ab	5.0 a	297 d	278.0 ab
		$N_0P_2K_2$	14.0 c	4.8 a	2.5 b	370 bc	272.0 ab
		$N_1P_2K_2$	14.4 bc	4.9 a	1.4 c	450 ab	267.0 abc
		$N_2P_2K_2$	15.1 b	4.6 ab	1.4 c	463 a	273.0 ab
		$N_3P_2K_2$	16.0 a	4.5 b	1.5 c	436 ab	300.0 a
	P_2O_5	$N_2P_0K_2$	13.7 bc	4.6 ab	1.6 a	308 c	262.0 ab
		$N_2P_1K_2$	15.6 a	5.0 a	1.0 c	445 ab	286.0 a
		$N_2P_2K_2$	15.1 a	4.6 ab	1.4 ab	463 a	273.0 ab
		$N_2P_3K_2$	14.4 b	5.0 a	1.0 c	456 a	286.0 a
	K_2O	$N_2P_2K_0$	14.0 b	4.6 ab	1.4 a	377 c	250.0 b
		$N_2P_2K_1$	15.0 a	4.8 a	1.5 a	400 bc	306.0 a
		$N_2P_2K_2$	15.1 a	4.6 ab	1.4 a	463 a	273.0 ab
		$N_2P_2K_3$	15.0 a	4.8 a	1.4 a	438 b	288.0 ab
HZY	N	$N_0P_0K_0$	16.7 b	4.5 bc	0.1 a	282 b	308.2 c
		$N_0P_2K_2$	16.3 b	4.3 c	0.2 a	275 b	316.5 bc
		$N_1P_2K_2$	18.0 a	5.3 ab	0.1 a	369 a	332.5 ab
		$N_2P_2K_2$	18.2 a	5.7 a	0.2 a	367 a	374.6 a
		$N_3P_2K_2$	16.7 b	4.7 b	0.2 a	371 a	363.4 ab
	P_2O_5	$N_2P_0K_2$	16.8 c	4.8 b	0.3 a	318 ab	328.4 b
		$N_2P_1K_2$	18.8 b	5.4 ab	0.1 ab	369 a	389.2 a
		$N_2P_2K_2$	18.2 b	5.7 a	0.2 a	367 a	374.6 ab
		$N_2P_3K_2$	19.9 a	5.6 a	0.1 ab	377 a	386.1 a
	K_2O	$N_2P_2K_0$	16.5 c	5.3 ab	0.3 a	303 c	376.0 a
		$N_2P_2K_1$	18.6 a	5.2 ab	0.3 a	337 ab	374.4 a
		$N_2P_2K_2$	18.2 ab	5.7 a	0.2 a	367 a	374.6 a
		$N_2P_2K_3$	18.5 a	4.5 b	0.2 a	316 abc	375.0 a

Note: Values followed by different lowercase letters are significantly in N, P and K treatments at the 5% level.

3.1.2 Yield and economic benefits. From Table 4, it can be seen that the application of nitrogen, phosphorus and potassium fertilizer can increase the yield of maize in two experimental plots. Except $N_0P_2K_2$ of HZY plot, the yield of other treatments was significantly higher than that of $N_0P_0K_0$ (CK). The yield under $N_2P_2K_3$ and $N_2P_1K_2$ was the highest in MHQ and HZY, respectively, which was 64.3% and 61.9% higher than that of the control, respectively. Comparing the yield increase of maize in MHQ and HZY, the average yield increased by 38.3% and 53.5% for nitrogen fertilizer, 7.0% and 59.0% for phosphorus fertilizer and 3.7% and 62.8% for potassium fertilizer, respectively. Although the maize in MHQ and HZY showed yield increase effect with the increase of nitrogen, phosphorus and potassium application rate, the yield increase rate was quite different, which might be related to the soil fertilizer and maize varieties in the two experimental plots.

The ratio of output to input takes into account the output and cost input (cost only refers to the cost of fertilizer, the rest of the input is consistent, not considered), which is related to the final income. Under the fertilization treatments of K_2P_2, N_2K_2 and N_2P_2, except that the ratio of output to input in HZY increased at first and then decreased with the amount of phosphorus applied, the ratio of output to input in the other treatments decreased with the increase of the amount of nitrogen, phosphorus and potassium applied. The highest ratio of output to input of all treatments in the two plots was in $N_0P_2K_2$, 12.3 and 10.6, respectively. The lowest ratio of output to input was in $N_3P_2K_2$ treatment, which was 5.0 and 4.6, respectively. Because the ratio of output to input is affected by yield and fertilizer price, the change of ratio of output to input is different.

Table 4 Effect of N/P/K on maize yield and economic benefits

Plot	Fertilizer	Treatments	Yield//kg/ha	Value//yuan/ha	Rate of growth//%	Fertilizer cost//yuan/ha	Income//yuan/ha	Input/output
MHQ	N	$N_0P_2K_2$	5 550 c	11 100 d	–	900	10 200 d	12.3 a
		$N_1P_2K_2$	6 833 b	13 667 c	23.1	1 674	11 993 c	8.2 b
		$N_2P_2K_2$	8 150 a	16 300 a	46.8	2 448	13 852 a	6.7 bc
		$N_3P_2K_2$	8 038 a	16 076 ab	44.8	3 222	12 854 b	5.0 c
	P_2O_5	$N_2P_0K_2$	7 433 bc	14 867 c	–	2 013	12 854 c	7.4 a
		$N_2P_1K_2$	7 767 b	15 533 bc	4.5	2 231	13 303 ab	7.0 ab
		$N_2P_2K_2$	8 150 a	16 300 a	9.6	2 448	13 852 a	6.7 b
		$N_2P_3K_2$	7 940 ab	15 881 b	6.8	2 666	13 215 b	6.0 bc
	K_2O	$N_2P_2K_0$	7 850 b	15 700 b	–	1 983	13 717 a	7.9 a
		$N_2P_2K_1$	8 050 ab	16 100 a	2.5	2 216	13 885 a	7.3 ab
		$N_2P_2K_2$	8 150 a	16 300 a	3.8	2 448	13 852 a	6.7 b
		$N_2P_2K_3$	8 217 a	16 433 a	4.7	2 681	13 753 a	6.1 c
HZY	N	$N_0P_2K_2$	4 758 d	9 517 c	–	900	8 617 c	10.6 a
		$N_1P_2K_2$	6 700 c	13 400 b	40.8	1 674	11 726 ab	8.0 b
		$N_2P_2K_2$	7 517 a	15 033 a	58.0	2 448	12 585 a	6.1 c
		$N_3P_2K_2$	7 375 ab	14 750 a	55.0	3 222	11 528 b	4.6 d
	P_2O_5	$N_2P_0K_2$	5 708 c	11 417 c	–	2 013	9 404 c	5.7 b
		$N_2P_1K_2$	7 692 a	15 383 a	34.7	2 231	13 153 a	6.9 a
		$N_2P_2K_2$	7 517 ab	15 033 a	31.7	2 448	12 585 ab	6.1 ab
		$N_2P_3K_2$	7 358 ab	14 717 b	28.9	2 666	12 051 b	5.5 bc
	K_2O	$N_2P_2K_0$	6 225 c	12 450 c	–	1 983	10 467 b	6.3 a
		$N_2P_2K_1$	6 900 b	13 800 b	10.8	2 216	11 585 ab	6.2 a
		$N_2P_2K_2$	7 517 a	15 033 a	20.7	2 448	12 585 a	6.1 a
		$N_2P_2K_3$	6 475 bc	12 950 c	4.0	2 681	10 270 b	4.8 b

Note: The price of fertilizer in the year of planting is equivalent to pure N 4.3 yuan/kg, pure P_2O_5 5.8 yuan/kg, pure K_2O 6.2 yuan/kg, local maize purchase price is 2 yuan/kg.

3.1.3 Correlation analysis. Through the correlation analysis between maize yield and maize agronomic index, it was found that the correlation coefficient between maize yield and ear length in MHQ was 0.685, indicating that there was a very significant positive correlation ($P<0.01$); the correlation coefficient with barren ear tip length was −0.704, showing a very significant negative correlation ($P<0.01$); the correlation coefficient with the number of kernels per panicle was 0.534, showing a significant positive correlation ($P<0.05$). The correlation coefficients between maize yield and ear length, ear diameter, kernel number per spike or kernel weight in HZY plot were 0.665, 0.685, 0.909 and 0.794, respectively, indicating that there was a very significant positive correlation ($P<0.01$), but maize yield was not significantly correlated with barren ear tip length. The results showed that the yield of maize in the two plots was significantly affected by ear length and kernel number per spike, while the differences in ear diameter, barren ear tip length and kernel weight might be mainly affected by varieties. Therefore, in the process of maize planting, reasonably selecting improved varieties, and adjusting the ratio of nitrogen, phosphorus and potassium fertilizers to improve ear length, ear diameter, barren ear tip length, kernel number per ear and kernel weight is beneficial to increasing maize yield.

3.2 Interaction effect of nitrogen, phosphorus and potassium fertilizer application level

3.2.1 Response of phosphorus and potassium fertilizers to nitrogen fertilizer. It can be seen from Fig. 1 that at K_2 level, the yield of maize under low nitrogen and medium nitrogen treatments decreased with the increase of phosphorus fertilizer application rate (except N_2 level in MHQ). At N_1 level in MHQ, the yield of maize decreased by 1 116.7 kg/ha, while at N_2 level, it increased by 383.3 kg/ha. The yield of maize in HZY decreased by 283.3 and 175.0 kg/ha, respectively. At P_2 level, comparing low potassium and medium potassium treatment, the yield of maize in MHQ under medium nitrogen and low nitrogen treatments increased by 100.0 and 450.0 kg/ha, respectively, and it increased in HZY by 616.7 and 750.0 kg/ha, respectively.

3.2.2 Response of nitrogen and potassium fertilizer to phosphorus fertilizer. It can be seen from Fig. 2 that when the application rate of potassium fertilizer is at K_2 level, the yield of maize in MHQ at low phosphorus level decreased by 183.3 kg/ha, while the yield of maize at medium phosphorus level increased by 1 316.7 kg/ha with the increase of nitrogen application rate. At the low and medium phosphorus levels, the yield of maize in HZY increased by 708.3 and 816.7 kg/ha, respectively. When the application rate of nitrogen fertilizer was at N_2 level, comparing medium and low potassium levels, the yield of maize in MHQ under low phosphorus and medium phosphorus treatments increased by 516.7 and 100.0 kg/ha, HZY, respectively, while the yield of maize in HZY increased by 1 291.7 and 616.7 kg/ha, respectively. It can be seen that nitrogen fertilizer can promote the role of phosphorus fertilizer in increasing yield, and the yield at the medium nitrogen and medium potassium level was higher than in other treatments, which indicated that nitrogen fertilizer was beneficial to the exertion of phosphorus fertilizer effect.

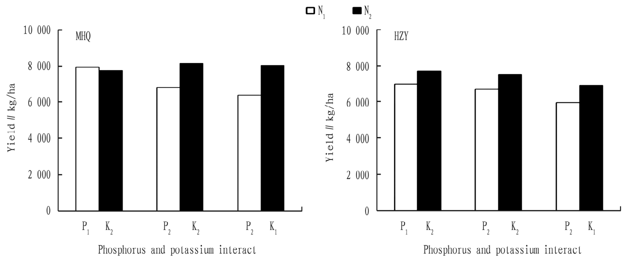

Fig. 1 Effect of different P and K on N

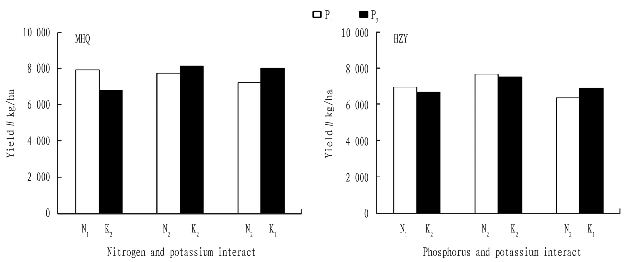

Fig. 2 Effect of different P and K on N

3.2.3 Response of nitrogen and phosphorus fertilizers to potassium fertilizers. From Fig. 3, it can be seen that at the medium potassium and low potassium levels, the yield was the highest at medium nitrogen and medium phosphorus levels, which indicated that the efficiency of potassium fertilizer can be brought into full play by rational application of nitrogen and phosphorus fertilizer. When the amount of phosphorus fertilizer was at P_2 level, the maize yield in MHQ and HZY increased by 1 666.7 and 950.0 kg/ha under the treatment of low potassium and medium nitrogen. The maize yield in MHQ and HZY increased by 1 316.7 and 816.7 kg/ha under the treatment of medium potassium and medium nitrogen. When the application rate of nitrogen fertilizer was at N_2, the yield of maize in MHQ and HZY increased by 800.0 and 500.0 kg/ha, respectively, comparing the medium and low phosphorus levels. The yield of maize in MHQ increased by 383.3 kg/ha, while the yield of maize in HZY decreased by 175.0 kg/ha under medium potassium treatment.

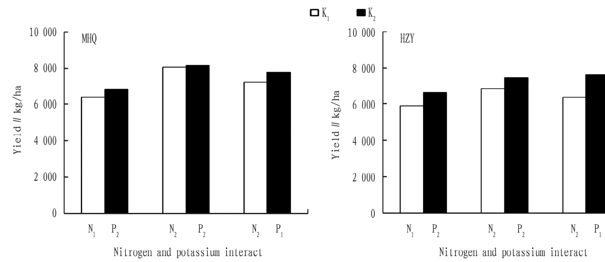

Fig. 3 Effect of different N and P on K

3.3 Fertilizer effect model and recommended fertilizer application rate It can be seen from Table 5 that the ternary quadratic fertilizer function of N, P and K in MHQ plot has passed the significance test of regression equation, and the quadratic fertilizer effect function of N in HZY plot has passed the significance test of regression equation. Therefore, the ternary quadratic fertilizer function model of N, P and K and quadratic fertilizer effect function model of N were used as recommended fertilization models for maize in the two experimental plots, respectively. The application rate for the highest yield in MHQ plot was: N 410.6 kg/ha, P_2O_5 80.7 kg/ha and K_2O 105.6 kg/ha. The corresponding yield was 8 114.8 kg/ha. The application rate for the highest yield in HZY plot was: N 419.7 kg/ha, P_2O_5 75 kg/ha and K_2O 75 kg/ha. The corresponding yield was 7 599.3 kg/ha.

Table 5 Fitting equation of fertilizer effect function

Plot	Factor	Experiment number	Equation	R^2	Maximum yield//kg/ha
MHQ	N	2, 3, 6, 11	$Y=-0.011X_N^2+10.7X_N+5\,476.9$	0.98	8 131.4
	P	4, 5, 6, 7	$Y=-0.096\,7X_P^2+16.0X_P+7\,400.9$	0.93	7 844.8
	K	6, 8, 9, 10	$Y=-0.024X_K^2+5.9X_K+7\,853.4$	0.91	8 216.8
	N-P-K	1 ~ 14	$Y=4\,995.4+5.8X_N-0.011X_N^2-21.1X_P-0.070X_P^2+52.8X_K+0.038X_K^2+0.158X_NX_P-0.087X_NX_K-0.308X_PX_K$	0.99*	8 114.8
HZY	N	2, 3, 6, 11	$Y=-0.016X_N^2+13.5X_N+4\,766.3$	1.00*	7 599.3
	P	4, 5, 6, 7	$Y=-0.381X_P^2+55.6X_P+5\,816.8$	0.91	7 844.8
	K	6, 8, 9, 10	$Y=-0.31X_K^2+38.0X_K+6\,145.0$	0.87	7 326.7
	N-P-K	1 ~ 14	$Y=4\,704.2+2.4X_N-0.014X_N^2-10.5X_P-0.232X_P^2+63.0X_K-0.339X_K^2+0.161X_NX_P-0.027X_NX_K-0.125X_PX_K$	0.92	7 205.5

4 Conclusions and discussions

The quality and yield of maize are affected and restricted by the population structure of crop and many factors in the production process[10-11]. Fertilization has the most direct and rapid influence on it among many influencing factors. The rational combination of nitrogen fertilizer, phosphorus fertilizer and potassium fertilizer is not only helpful to the growth and morphogenesis of maize, but also helpful to establishing a good population structure, and significantly increasing crop yields[12]. The results showed that different maize varieties were planted in two experimental plots with different soil quality and fertility, and the changes of ear length, ear diameter, kernel number per ear, barren ear tip length and kernel weight were promoted by fertilizer application, and then the yield and net income of maize were affected. Correlation analysis also confirmed that maize yield was affected by ear length, ear diameter, kernel number per ear, barren ear tip length and kernel weight. Although the influencing factors are different, this may be related to the difference in variety and soil fertility factors.

Except that the yield, output value and income of maize increased with the increase of potassium application in MHQ plot, the yield, output value and income of the two maize varieties increased at first and then decreased with the increase of fertilizer application rate. The average yield increase rate of nitrogen fertilizer was 38.3% and 53.5%, respectively; the average yield increase rate of phosphorus fertilizer was 7.0% and 59.0%, respectively; the average yield increase rate of potassium fertilizer was 3.7% and 62.8%, respectively. Although the increase of nitrogen, phosphorus and potassium application rate showed the effect of increasing maize yield, the yield increase rate of maize in the two plots was quite different, which might be related to the soil fertility of the plot and maize varieties.

Overall, when fertilization exceeded a certain range, maize yield and economic effects will no longer increase, but have a downward trend. This accords with the law of diminishing return of fertilizer[13], which is consistent with the study of Niu Guiyu *et al.*[14-15].

The results showed that the fitting functions of the highest yield of the two maize varieties were different in the fitting of fertilizer effect in the two plots. The ternary quadratic fertilizer function model of N, P and K and quadratic fertilizer effect function model of N were used as recommended fertilization models for maize in the two experimental plots (MHQ and HZY), respectively. The application rate for the highest yield in MHQ plot was: N 410.6 kg/ha, P_2O_5 80.7 kg/ha and K_2O 105.6 kg/ha. The corresponding yield was 8 114.8 kg/ha. The application rate for the highest yield in HZY plot was: N 419.7 kg/ha, P_2O_5 75 kg/ha and K_2O 75 kg/ha. The corresponding yield was 7 599.3 kg/ha.

References

[1] WANG XC, ZHU LJ. Analysis on the effect of soil formula fertilization on corn "3414" in Luquan County[J]. Yunnan Agriculture, 2014, 29(9): 40-41. (in Chinese).
[2] HUANG YB, SUN LY, HUANG Y, *et al.* Experiment on "3414" soil testing and formulated fertilization on rice[J]. Barley and Cereal Sciences, 2012, 29(1): 30-34. (in Chinese).
[3] JI L, ZHANG XZ, LI TX. Establishing fertilization recommendation index of paddy soil based on the "3414" field experiments in the middle of Sichuan hilly regions[J]. Scientia Agricultura Sinica, 2011, 44(1): 84-92. (in Chinese).
[4] LI Y, WANG JJ, ZHAO GC, *et al.* Experimental study on field fertility of wheat 3414[J]. Barley and Cereal Sciences, 2011, 28(3): 51-53. (in Chinese).
[5] HUANG Y, LI TX, ZHANG XZ, *et al.* Establishment of fertilization recommendation indexes of rapeseed soil based on the "3414" field experiments in the middle of Sichuan hilly regions[J]. Scientia Agricultura Sinica, 2013, 46(10): 2058-2066. (in Chinese).
[6] LU ZG, ZHOU L, YANG LM. Effect of different fertilization levels on barley yield and fertilizer effect[J]. Journal of Shandong Agricultural University, 2018, 49(5): 1-6. (in Chinese).
[7] GUO LL. Effect of "3414" formula fertilization on yield and nutrient absorption of maize[J]. Journal of Shanxi Agricultural Sciences, 2015, 43(5): 576-578, 633. (in Chinese).
[8] CHEN ZH, WU YF, GUO HL. Study on optimal fertilizer rate for main spring maize production area in Hunan Province[J]. Crop Research, 2016, 30(1): 22-27. (in Chinese).
[9] SHEN XS, CHEN SH, CHEN HL, *et al.* Study on effects of "3414" model on nitrogen phosphorus and potassium of maize in hilly regions of Middle Sichuan[J]. Southwest China Journal of Agricultural Sciences, 2012, 25(5): 2132-2137. (in Chinese).
[10] GAO ZH, CHEN XY, LIN CH, *et al.* Effect of fertilizer application rates on cassava N, P, K accumulations and allocation and yield in sloping lands of North Guangdong[J]. Scientia Agricultura Sinica, 2011, 44(8): 1637-1645. (in Chinese).
[11] WANG Z, GAO RF, LI WX, *et al.* Effect of nitrogen, phosphorus and potassium fertilizer combined application on dry matter accumulation and yield of soybean[J]. Soybean Science, 2008, 27(4): 588-592. (in Chinese).
[12] GONG YQ, BAI JY, HOU XN, *et al.* Study on the optimum amount and proportion of nitrogen, phosphorus and potassium fertilizer in low and medium yield rice[J]. Ningxia Journal of Agriculture and Forestry Science and Technology, 2007, 50(3): 7-9. (in Chinese).
[13] DONG SQ. Study on the effect of the different ration of nitrogen, phosphorus and potassium on rice output by the "3414" design[J]. Chinese Countryside Well-off Technology, 2006, 10(12): 60-62. (in Chinese).
[14] ZHU GY, OU HP, HE J, *et al.* The research of fertilizer effect on the no-tillage cultivated rice based on experiment of "3414" design[J]. Soil and Fertilizer Sciences in China, 2011, 48(5): 48-52. (in Chinese).
[15] ZHAI GD, WANG H, LIU XW, *et al.* "3414" fertilizer efficiency experiment of late rice and the recommended fertilizer amount in Southeastern Hubei[J]. Journal of Hebei Agricultural Sciences, 2009, 13(10): 29-31, 34. (in Chinese).

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[2] ZHAO LC, WANG Y, FENG Y, *et al.* Effects of type and formula of antioxidant on shelf life of cold-pressed *Cannabis* oil[J]. China Oils and Fats, 2017, 42(12): 49-50. (in Chinese).
[3] T/CNFIA 001-2017. General guideline for food shelf life[S]. (in Chinese).
[4] WANG EG, LIU WM. The change law and mathematical model analysis of rice pest population after changing 'double cropping' to 'single cropping'[J]. Journal of Agriculture, 2014, 4(3): 14-19. (in Chinese).
[5] JIANG WH, LI HD, CHENG XF, *et al.* Study on host plants for reproduction of *Chilo suppressalis*[J]. Journal of Asia-Pacific Entomology, 2015, 18(3): 591-595.
[6] LIU XB, XIE LH, TANG SQ, *et al.* Evaluation of appraisement method for rice resistance to striped stem borer[J]. China Rice, 2016, 22(4): 35-38. (in Chinese).
[7] DAI CG, OUYANG F, CHEN XY, *et al.* Development of artificial rearing technology for Lepidoptera insects[J]. Journal of Southern Agriculture, 2016, 47(5): 672-676. (in Chinese).
[8] LI B, HAN LZ, PENG YF. Development of a standardized artificial diet and rearing technique for the striped stem borer, *Chilo suppressalis* Walker (Lepidoptera: Crambidae)[J]. Chinese Journal of Applied Entomology, 2015, 52(2): 498-503. (in Chinese).
[9] HU Y, ZHENG YL, CAO GL, *et al.* A technique for rearing *Chilo suppressalis* in the large scale with an oligidic diet in laboratory[J]. Chinese Journal of Rice Science, 2013, 27(5): 535-538. (in Chinese).
[10] NI Y, DAI CG, TONG XY, *et al.* Effects of moisture content and quantity in the artificial diet on growth and development of *Chilo suppressalis*[J]. Guizhou Agricultural Sciences, 2016, 44(8): 45-47. (in Chinese).
[11] LI X, WANG W, LIU DY, *et al.* Terminal study on the food storage of cold chain management[J]. The Food Industry, 2013, 34(6): 154-158. (in Chinese).
[12] HE YY, MA P, LIU XL, *et al.* Effect of different initial pH on the storage characteristics and shelf life of liquid diet for suckling and weanling piglets[J]. Journal of Integrative Agriculture, 2014, 13(1): 134-139.
[13] ZHANG SK, WANG YC, SU JY, *et al.* Inhibitory effects of antifungal agents against *Aspergillus* on the artificial diets of rice leaffolder, *Cnaphalocrocis medinalis*[J]. Journal of Nanjing Agricultural University, 2014, 37(2): 59-66. (in Chinese).