## Title
Potassium Fertilization Rates for Maximum Economic Return for Maize Production under Different Soil Available K Levels in Jilin Province of China



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## Introduction

Jilin province is located in the Northeast of China with east longitude from 121°38' to 131°19' and north latitude from 40°52' to 46°19', and is known as the “maize belt” of China. In recent years, the planting area of maize in Jilin province accounted for more than 10% of the total maize planting area of China, and the production accounted more than 15% of the total production. Because of its importance to China’s grain supply and food security, great attention has been paid to high yield maize production with increased inputs, including fertilizers, in the province. However, with the cost of input materials increasing, and relatively low price of maize grain, the overall benefit of growing maize in the region is relatively low (Zhang, 2005).

Potassium is one of the major nutrients for plant growth and plays an important role in high yield and high quality crop production. In recent years, with increases in crop yield and increased use of nitrogen (N) and phosphorous (P) fertilizers, soil K reserves had been gradually depleted, and an insufficient supply of soil available K has become one of the major limiting factors for high yield maize production in the “maize belt” of China (Cui, 2002; Wang, 2004; Xie, 2006). However, fertilizer use in the region is still not well balanced, with relatively low rate of K fertilizer application (Wu, 2001).

To obtain maximum returns from potassium fertilizer input, it is important to understand the proper potassium fertilizer rate for maize production under different soil fertility levels and for different maize yield goals. In this paper, proper potassium fertilization rates for high yield maize production and maximum economic returns were studied in selected field sites in the main maize production regions in Jilin province of China from 2001-2008.

## Material and Methods

A total of 16 field experiments were conducted from 2001 to 2008. The field sites were selected from the main maize production counties across the province, from Yushu County in the north to Lishu County in the south, with Gongzhuling and Yitong counties in the middle. The soil type was black earth with different fertility and productivity levels. The location and chemical properties of the soil samples taken at 0-20 cm from the experimental field sites are shown in Table 1. Soil pH was determined using a pH meter with a 1:1 soil to water ratio; soil organic matter was determined by potassium dichromate oxidization method; soil available N was estimated by an alkaline dissolved N determination; soil available P was determined by the Olsen procedure; and soil available K ($NH_4Ac$-K) was extracted with 1 mol/L $NH_4OAc$ and determined by atomic absorption spectrophotometer (Soil Science Society of China, 2000).

High yield maize varieties which were locally adapted were selected for each field experiments with populations ranging from 50,000 to 65,000 plants per hectare.

Five or six K rate treatments were used for each experiment based on the yield goal and the soil condition (Table 1). A randomized complete block design was used for all experiments with 3 or 4 replications.

Table 1. Chemical properties of top soil samples from selected sites and $K_2O$ rates

| Year | Location | pH | OM (%) | Avail N (mg/kg) | Avail P (mg/kg) | Avail K (mg/kg) | Treatment Rates ($K_2O$, kg/ha) |
|---|---|---|---|---|---|---|---|
| 2001 | Liufangzi, Gongzhuling Co. | 5.3 | 2.35 | 142.8 | 16.4 | 89.0 | 0,25,50,75,100 |
| 2002 | Liufangzi, Gongzhuling Co. | 6.4 | 2.15 | 150.4 | 12.1 | 82.0 | 0,60,90,120,150 |
| 2002 | Lishu, Lishu Co. | 6.6 | 1.94 | 132.9 | 17.7 | 99.5 | 0,60,90,120,150 |
| 2003 | Liufangzi, Gongzhuling Co. | 5.6 | 1.99 | 91.7 | 12.5 | 98.8 | 0,60,90,120,150 |
| 2003 | Fengxiang, Gongzhuling Co. | 6.5 | 2.46 | 113.3 | 2.1 | 123.4 | 0,60,90,120,150 |
| 2003 | Liufangzi, Gongzhuling Co. | 5.6 | 1.99 | 91.7 | 12.4 | 96.8 | 0,60,90,120,150 |
| 2004 | Gongzhuling Co. | 5.6 | 1.94 | 180.8 | 17.9 | 134.8 | 0,60,90,120,150 |
| 2005 | Gongpengzi, Yushu Co. | 6.0 | 2.72 | 135.9 | 8.57 | 128.5 | 0,30,60,90,120 |
| 2006 | Wanfa, Lishu Co. | 6.0 | 1.70 | 153.9 | 13.26 | 77.3 | 0,50,75,100,150 |
| 2007 | Yangdachengzi, Gongzhuling Co. | 5.9 | 1.45 | 92.55 | 19.65 | 93.9 | 0,25,50,75,100,125 |
| 2007 | Kaoshan, Yitong Co. | 5.7 | 2.30 | 145.2 | 26.02 | 113.9 | 0,25,50,75,100,125 |
| 2008 | Gongpengzi, Yushu Co. | 6.1 | 2.74 | 201.5 | 34.48 | 198.2 | 0,30,60,90,120 |
| 2008 | Huancheng,yushu Co. | 5.2 | 2.45 | 156.9 | 34.22 | 122.3 | 0,30,60,90,120 |
| 2008 | Fanjiatun, Gongzhuling Co. | 6.4 | 2.40 | 143.9 | 26.39 | 120.2 | 0,30,60,90,120 |
| 2008 | Fengxiang,Gongzhuling Co. | 6.5 | 2.15 | 133.0 | 22.11 | 112.9 | 0,30,60,90,120 |
| 2008 | Shijiapu. Lishu Co. | 5.2 | 1.73 | 107.1 | 16.26 | 122.0 | 0,30,60,90,120 |

Plot size was 20 $m^2$ for all experiments. Potassium chloride was used for the K treatments applied with band application at planting. All plots received the same amount of N and P fertilizers. Secondary and micro nutrients were also added to all plots when deficient as indicated by soil testing.

All experiments were planted on May 10-15, and harvested from September 25 to October 6 in all years of the study. The experimental fields were managed as normal high yield maize production fields in the region.

Regression analysis for maize yield response function to K application rate was done with SPSS software with maize yield, $K_2O$ rates, cost of K fertilizer and price of maize as input parameters. The maximum yield, $K_2O$ rate for the maximum yield (MY), maximum economic yield (MEY, yield with maximum net return calculated by the regression analysis), $K_2O$ rate for MEY, and net benefit of K fertilization was calculated with a self-developed program using Excel and the principle described by J. D. Colwell (1978). Actual prices of maize grain and potassium chloride fertilizer at the time the field experiments were conducted were used for economic analysis.

## Results and Discussion

For all field experiments, relationships between $K_2O$ application rate and maize yield were well described by quadratic functions (Fig 1).

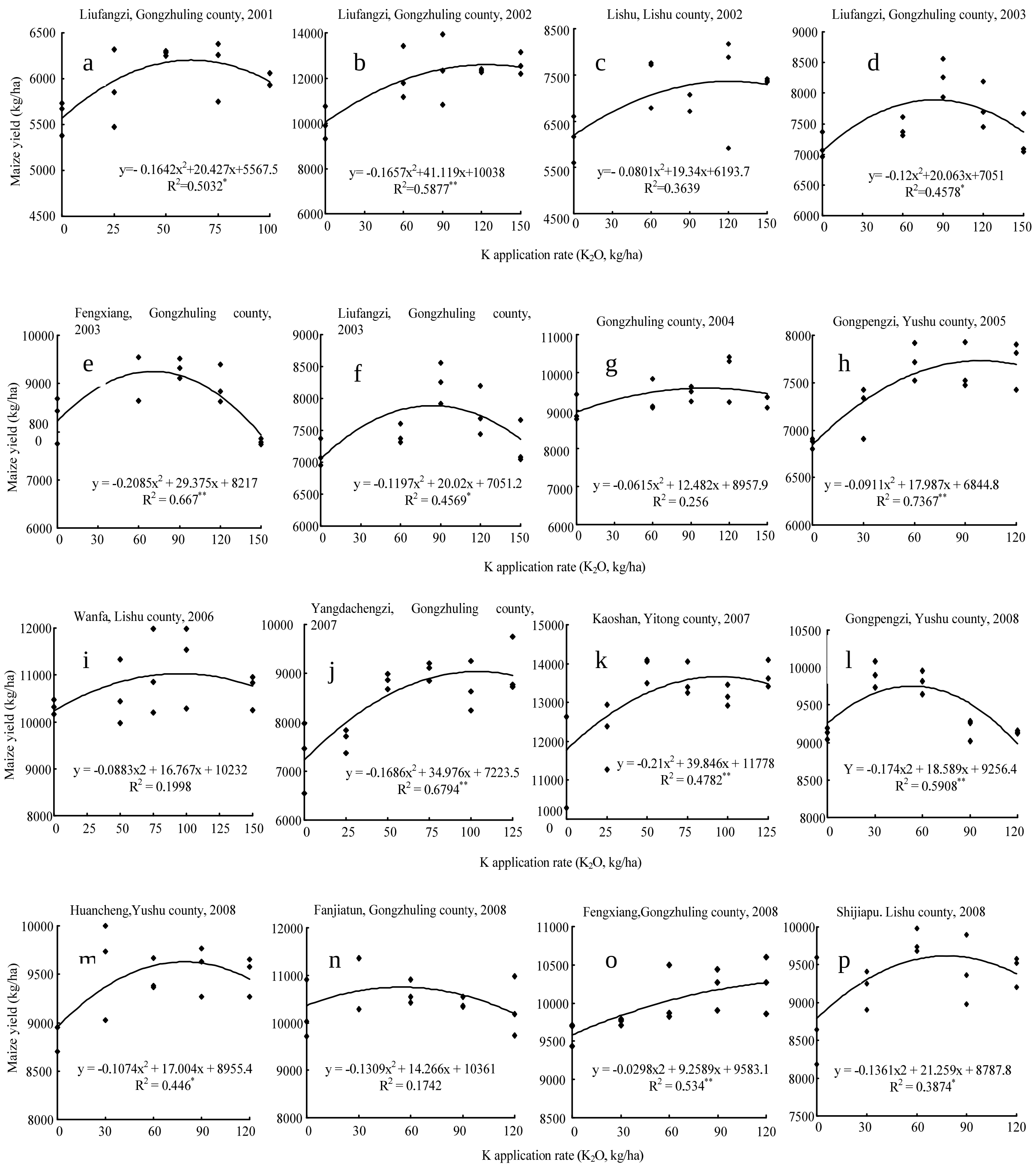


Fig 1. Maize yield response curve to K application at different sites in Jilin

( * Significant at the 0.05 level ; ** Significant at the 0.01 level. )

The maximum yield estimated from the quadratic equations (MY) ranged from 6203 kg/ha in the 2001 experiment in Liufangzi, Gongzhuling County (Fig 1-a) to 13668 kg/ha Kaoshan, Yitong County in 2007 (Fig 1-k). The $K_2O$ application rate to reach the MY ranged from 53.4 kg/ha in Gongpengzi of Yushu County in 2008 with the maximum yield of 9753 kg/ha (Fig 1-l), to 155.4 kg/ha in Fengxiang site in Gongzhuling in 2008 with maximum yield of 10302 kg/ha (Fig 1-o) (Table 2). From 1994 to 1996, Wu W. et al. (1998) had conducted 8 field experiments in 3 soil types in Jilin province, and reported that the proper rate for maximum maize yield at that time was 50-100 kg/ha. Results in our study indicated that the K rate for maximum maize yield production in the province may have increased in recent years. The possible reason is that in recent years maize yield increased gradually with increased soil K removal. However, the removed soil K was not replenished with either K fertilizer application and/or straw return, resulting in depletion of soil K reserves (Gao, 2001； Han,2007). In 2007, the average maize yield in Jilin was 6307 kg/ha (China Statistics Year Book, 2008), while the maximum yields obtained in this study from 2007 to 2008 ranged from 9037 kg/ha to 13668 kg/ha, indicating a great potential for further yield improvement by balanced use of K fertilizer along with other best management practices (Table 2).

The maximum economic yield (MEY) ranged from 6187 kg/ha in the 2001 experiment in Liufangzi, Gongzhuling County to 13660 kg/ha Kaoshan, Yitong County in 2007. The $K_2O$ application rate to reach the MEY ranged from 37.6 kg/ha in Fanjiatun site in Gongzhuling County in 2008 with the maximum economic yield of 10712 kg/ha to 115.5 kg/ha Liufangzi site in Gongzhuling in 2002 with maximum economic yield of 12577 kg/ha (Table 2).

The agronomic efficiency of $K_2O$ application from K fertilizer (AE = maize yield increase in kg with one kg of $K_2O$ application) ranged from 6.3 kg maize grain produced with one kg $K_2O$ application in Wanfa site of Lishu County in 2006, to 22.0 kg grain/kg $K_2O$ application at Liufangzi site in Gongzhuling in 2002 (Table 2).

The net benefit and the value and cost ratio (VCR) were affected by the changing price in both maize grain and K fertilizer. Analysis indicated that the highest benefit from K fertilizer application appeared from the field trial in Kaoshan, Yitong County in 2007 with net benefit of 1977 Yuan/ha (290.7US$/ha) and VCR 8.0. The lowest benefit from K fertilizer application appeared from the field trials in Gongzhuling County in 2008 with net benefit of 264-280 Yuan/ha (38.8-41.2 US$/ha) and a VCR value of 2.1-1.5 (Table 2). One important factor for the relatively low net benefits for all field trials in 2008 is the remarkable increase of K fertilizer price in 2008, which doubled from the price in 2007.

Table 2. $K_2O$ rates for maximum yield and maximum economic maize yield

| Year | Location | Max. Yield (MY, kg/ha) | K Rates for MY ($K_2O$, kg/ha) | Max. Econ. Yield (MEY, kg/ha) | K rate for MEY ($K_2O$, kg/ha) | AE at MEY (kg/kg) | Net benefit (Yuan /ha)* | VCR |
|---|---|---|---|---|---|---|---|---|
| 2001 | Liufangzi, Gongzhuling Co. | 6203 | 62.2 | 6187 | 52.4 | 11.8 | 360 | 3.7 |
| 2002 | Liufangzi, Gongzhuling Co. | 12589 | 124.1 | 12577 | 115.5 | 22.0 | 1813 | 7.7 |
| 2002 | Lishu, Lishu Co. | 7361 | 120.7 | 7336 | 103.0 | 11.1 | 697 | 3.9 |
| 2003 | Liufangzi, Gongzhuling Co. | 7890 | 83.6 | 7878 | 73.8 | 11.2 | 537 | 4.8 |
| 2003 | Fengxiang, Gongzhuling Co. | 8872 | 56.1 | 8866 | 50.7 | 12.8 | 461 | 5.7 |
| 2003 | Liufangzi, Gongzhuling Co. | 7888 | 83.6 | 7878 | 74.3 | 11.3 | 568 | 5.0 |
| 2004 | Gongzhuling Co. | 9591 | 101.5 | 9560 | 78.9 | 7.6 | 345 | 2.8 |
| 2005 | Gongpengzi, Yushu Co. | 7733 | 98.7 | 7711 | 83.4 | 10.4 | 633 | 3.7 |
| 2006 | Wanfa, Lishu Co. | 11028 | 95.0 | 11008 | 80.0 | 9.7 | 678 | 3.7 |
| 2007 | Yangdachengzi, Gongzhuling Co. | 9037 | 103.7 | 9027 | 95.9 | 18.8 | 1860 | 7.1 |
| 2007 | Kaoshan, Yitong Co. | 13668 | 94.9 | 13660 | 88.6 | 21.2 | 1977 | 8.0 |
| 2008 | Gongpengzi, Yushu Co. | 9753 | 53.4 | 9725 | 40.7 | 11.5 | 412 | 2.6 |
| 2008 | Huancheng,yushu Co. | 9628 | 79.2 | 9583 | 58.6 | 10.7 | 527 | 2.4 |
| 2008 | Fanjiatun, Gongzhuling Co. | 10750 | 54.5 | 10712 | 37.6 | 9.4 | 264 | 2.1 |
| 2008 | Fengxiang,Gongzhuling Co. | 10302 | 155.4 | 10138 | 81.1 | 6.8 | 280 | 1.5 |
| 2008 | Shijiapu. Lishu Co. | 9618 | 78.1 | 9582 | 61.8 | 12.8 | 744 | 2.9 |
| | CV (%) | 20.3 | 30.9 | 20.4 | 30.0 | 35.6 | 75.9 | 47.5 |

*The prices used for economic analysis:
-Maize grain: 0.8 Yuan/kg in 2001, 0.82 Yuan/kg in 2002, 0.86 for 2003, 0.90 Yuan/kg for 2004, 1.00 for 2005, 1.2 Yuan/kg for 2006-2007, 1.43 Yuan/kg for 2008. …
-$K_2O$ in fertilizer 2.58 Yuan/kg in 2001, 2.33 Yuan/kg for 2002, 1.92 Yuan/kg for 2003, 2.50 Yuan/kg for 2004, 2.80 Yuan/kg for 2005, 3.17 Yuan/kg for 2006-2007, 6.33 Yuan/kg for 2008.
- 1 $US equal to 6.8 Yuan in 2008, while 1 US$ equal to 8.26 Yuan in 2001.

From the results the general trend was also observed that with the decrease of soil available K level from Yushu County in northern Jilin to Gongzhuling and Lishu in the southern part of the province, the proper rate of $K_2O$ for MEY production of maize was generally increased along with an increase of overall net benefit of K application (Fig 2, Table 1 and Table 2). However, soil K supply capacity is not only determined by soil available K levels, but also influenced by the dynamic transformation of K in soils among various forms, such as between slowly available forms to more readily available forms. Further research is needed for better understanding and estimation of K supply capacity of soils from different regions of the province.

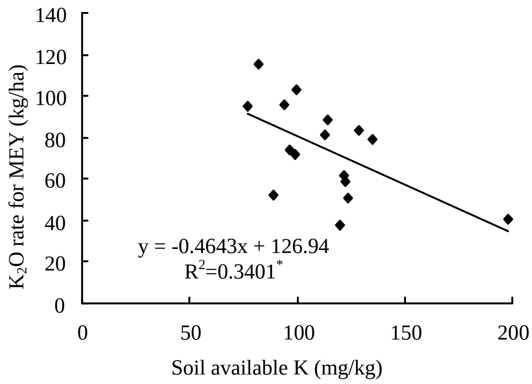


Fig. 2. Relationship of soil K available K level and proper $K_2O$ rate MEY of maize

( * indicates significant correlation at the 0.05 level )

## Conclusion

Field experiments conducted in the main maize production region of Jilin province, China from 2001 to 2008 indicated that sufficient supply of K fertilizer along with balanced management of N, P and other needed nutrients increased maize yield significantly.

Application of $K_2O$ at rates from 53.4 kg/ha to 155.4 kg/ha to different field sites with different soil available K levels can produce maximum maize yields from 6203 kg/ha to 13668 kg/ha in the region, indicating a great potential for further yield increase in maize production in the province.

The maximum economic yield level was determined by soil fertility, soil productivity, fertilizer input, price of fertilizers and maize grain. Results from these field experiments indicated that under the current conditions (including soil fertility, soil productivity, fertilizer input, price of fertilizers and maize grain) in the main maize production region in Jilin, the proper rate of $K_2O$ for the maximum economic return ranged from 37.6 kg/ha to 115.5 kg/ha, resulting in maximum economic yield from 6187 kg/ha to 13660 kg/ha, with net benefit of from 264 Yuan/ha (38.8 US$/ha) to 1977 Yuan/ha (290.7US$/ha), and a VCR value of 1.5 to 8.0.

As expected for soils with relatively low soil available K level, especially in the southern counties in the province with higher yield potentials due to warmer temperature and longer growing season, higher $K_2O$ rates were recommended; while for soils with relatively high soil available K level, especially in the northern regions, lower rates of $K_2O$ were recommended. Use of soil testing can be effective in improving distribution of limited K fertilizer thereby improving overall benefit to farmers.

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