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RESEARCH ARTICLE

Long-term application of K fertilizer and straw returning improve crop yield, absorptive capacity of K, and soil nutrient natural supplying capacity in North China

Limin SUN[1,4], Chunjie LI (✉)[2], Ping HE[3], Mengchao LIU[2], Jinghui HU[4]

[1] College of Resource and Environmental Sciences, Agricultural University of Hebei, Baoding 071001, China
[2] Institute of Agro-resources and Environment, Hebei Academy of Agriculture and Forestry Sciences, Shijiazhuang 050051, China
[3] Agricultural Resources and Regional Planning Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China
[4] Agricultural Information and Economic Research Institute, Hebei Academy of Agriculture and Forestry Sciences, Shijiazhuang 050051, China

Abstract **With the aim of increasing the grain crop yield and the level of soil nutrition in the fluvo-aquic soil in North China, the effects of long-term application of K fertilizers and straw returning on crop yield and soil nutrient supplying capacity were investigated in the long-term K localization experiment (1992–2009). The results revealed that wheat and maize responded to K fertilizer in an identical manner and the average yield of wheat and maize for 17 years were NPKSr > NPK > NPSr > NP. Application of K fertilizer on the basis of NP fertilizers could increase the yield of wheat and maize while the grain and straw yields in each treatment were significantly higher for maize than for wheat. The yield of wheat and maize was increased by 6.74% and 22.32% respectively when applied with NPK fertilizers compared to NP fertilizers. With the NPSr fertilizing mode, the yield of wheat and maize was increased by 2.84% and 10.62% compared to the NP mode respectively. The NPKSr fertilizing mode gave the best yield for wheat and maize, resulting in 10.34% and 23.81% increase respectively compared to the NP mode. The yield stability of wheat was significantly higher than that of maize. Under the condition of long-term fertilization, the K uptaken by wheat and maize was degressive by the sequence of NPKSr > NPSr > NPK > NP, mainly deposited in the straw but not in the grain. In this work, the soil natural ability for applying K was gradually reduced as the planting years proceeded and the changes were fitted by linear equations. The natural supply ability of K element in land planted wheat was higher than that in land planted maize.**

Keywords long-term fertilization, fluvo-aquic soil in North China, crop yield, K uptake, the soil nutrient natural supply capacity

Introduction

Soil potassium (K) is the most important and direct potassium source for crop growth and development. Whether the crops can get enough potassium for their normal growth, development, yield-building and quality improvement depend on K content in the soil. Wheat-maize rotation is one of the main planting system in the North China Plain. Applying K fertilizer plays a significant role to improve the yield, quality and disease resistance of winter wheat (Tan and Jie, 1996). In the past few years people have emphasized the application of nitrogen fertilizer and phosphatic fertilizer while no or little potash fertilizer has been used by the farmers. Due to the application of high-yielding crop varieties, which has been enhancing the yield and increasing the multi-planting index, the balance of potassium in soil has appeared to be affected, resulting in the serious lackage of potassium with an unceasingly expanding trend. This situation prohibits the further development of agricultural production. There are about 203.1×10^4 hm^2 chiltern fluvo-aquic soils in the Huanghuaihai Plain, with a lower rapidly-available potassium content, poorer retention of water and fertilizer performance and blindly applied fertilizers by farmers. Excess fertilizers

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Correspondence: Chunjie LI.
E-mail: liminsun@163.com

are wasted away very seriously (Wan et al., 1995; Kou et al., 2003; Liu et al., 2003; Zhang et al., 2007). Therefore, the study on potassium fertilization is of great importance for achieving high quality and efficient production of winter wheat. Tan et al. (2001), Han et al. (1998) and Yu et al. (2007) have studied the characteristics of K supplying, and potassium nutrition rules of winter wheat and their effects on the yield and quality of winter wheat in tidal soil. In a long-term experiment, Wang et al. (2010) found that the average yield of winter wheat could only reach 5.5 t/hm^2 and the potassium nutrient showed a severely deficiency when only nitrogen and phosphorus fertilizers were applied. However, the average yield of winter wheat was increased by more than 10.2% when potash fertilizer (K_2O 150 kg/hm^2) was applied in addition to the nitrogen and phosphorus fertilizers. An increase of above 6.6% in the average yield of winter wheat was obtained by wheat straw returning based on the nitrogen and phosphorus fertilizers. When the both fertilizing mode was applied, the average yield was increased by 17.6% and the average annual potassium absorption was increased to 32.0 kg/hm^2. Li et al. (2006) reported that the average yields of maize and wheat for 14 years were increased by 12% with the application of NPK + M compared to that with NPK while no significant difference in yields was observed between NPK + S and NPK. Long-term application of potassium and straw returning on the basis of nitrogen and phosphorus could remarkablely increase the yield of wheat and maize (Tan et al., 2008a). The crop yield was increased in the same way under Ningxia rotation cropping system, namely by the straw returning with NPK fertilizer > only NPK fertilizer application > straw returning with NP fertilizer > only NP fertilizer. Wheat had higher yield variable coefficient than maize, with less response to potash (Tan et al., 2008b). The effect became obvious 8–10 years after the K application, the practice of straw returning plus potash appear to be most effective, increasing K absorptive capacity of grain and straw. The K content in straw was rich, while grain had only 13%–17% of the total (Tan et al., 2009). Soil natural ability for K supplying decreased from 100% to 90% when no K fertilizer was applied for 11 years in the typical farmland soil (Wang et al., 2003). Previous studies have been focused on the effect of K fertilizer application and its amount on the yield and quality of crops (Jiang et al., 2004; Liang, 2004), and on the short-term impact on soil nutrient. As the evaluation of potash effect based on the data obtained from the short-term experiments is uncomprehensive, long-term positioning method is an effective way to study the influence of fertilization on crop yield, nutrients and K element of soil (Shen, 1995). The soil nutrient natural supply capacity is an important index of soil fertility evaluation (Zhao et al., 2009), and is the basis of scientific fertilization consists of soil testing and formulated fertilization, and balanced fertilization. However, there are fewer reports on the effect of long-term fertilization on crop yield and the evolving system of yield responding to straw returning. In the present work, we used long-term location experiments to study the effect of K application on crop yield, absorption of nourishment and soil nutrient natural supply capacity.

Materials and methods

Experiment design

The study was carried out in Xinji Malan Farm, Testing Ground of Institute of Agro-resources and Environment of Hebei Academy of Agriculture and Forestry Sciences, China, with light loamy soil, 8.7 mg/kg organic substance, 83.2 mg/kg rapidly-available K, 69.7 mg/kg rapidly available N, 12.6 /kg available P, 24. 4 g/kg potassium, 916.0 mg/kg slowly available K in the 0–20 cm topsoil, and 5.5 mg/kg organic substance, 88.0 mg/kg rapidly-available K, 48.3 mg/kg rapidly available N, 3.2 mg/kg available P, 25.4 g/kg potassium and 862.0 mg/kg slowly available K in the 20–40 cm soil. The experiment was consecutively conducted for 17 years (1992 to 2009) by using wheat-maize rotation in four treatments with only NP fertilizer application (NP); straw returning on the basis of NP (NPSr), where Sr is wheat straw used for fertilization returning at 7500 kg/hm^2 (dry weight, about 102 kg/hm^2 K_2O); K fertilizer application on the basis of NP (NPK); and straw and K fertilizer application on the basis of NP (NPKSr). The experiments were performed with 4 replications, with the pilot area of 50 m^2. The strategy for fertilizing was showed in Table 1. Wheat was sown usually in early October, and harvested in early June the next year and maize was usually sown in mid-June, and harvested in late September.

Sample detection methods

Rapidly-available potassium in soil was extracted using ammonium acetate and measured by flame photometer. Data processing and analysis of variance were done using

Table 1 Fertilization design

Treatments	Fertilizing amount for wheat (kg/hm^2)	Fertilizing amount for maize (kg/hm^2)
CK (NP)	N 225, P_2O_5 90	N 225, P_2O_5 90
NPK	N 225, P_2O_5 90, K_2O 150	N 225, P_2O_5 90, K_2O 150
NP + Sr	N 225, P_2O_5 90	N 225, P_2O_5 90, Wheat straw 7500
NPK + Sr	N 225, P_2O_5 90, K_2O 150	N 225, P_2O_5 90, K_2O 150, Wheat straw 7500

Data are from Xing et al. (2008, 2010).

Microsoft Excel and DPS, with significant differences between treatments detected by Duncan.

The soil nutrient natural supply capacity = (crops straw production × one element concentration) + (crop grain yield × one element concentration). In this experiment, the natural ability of soil to supply potassium was calculated as NP treatment

Soil natural ability for applying nutrient = crop yield when lack of an element/crop yield when full of nutrient × 100.

Results

The effect of long-term fertilization on the yield of wheat and maize grain

The results revealed that the average yield of both wheat and maize for 17 years showed an order as NPKSr > NPK > NPSr > NP (Table 2) when using this four type of fertilizing modes. Responses of wheat and maize to the K were identical. Their responses to the different fertilizer processing exhibited the following characteristics:

Applying K fertilizer on the basis of NP increased the yield of wheat and maize while the increases in the yield of maize grain and straw were significantly higher than those in wheat respectively. The wheat yields were increased by 6.74%, 2.84% and 10.34% by NPK, NPSr, and NPKSr respectively compared to the control NP treatment. The differences in yield of wheat between NPK, NPKSr and NP were significant while no obvious difference between NPSr and NP was observed, indicating that application K has the promoting effect on wheat yield while only straw returning has no effect on wheat yield based on the NP. On the other hand, the increase of 22.32%, 10.62%, and 23.81% in maize yield were obtained with NPK, NPSr, and NPKSr respectively compared to the control NP treatment. The differences in yield of maize between NPK, NPSr, NPKSr and NP were significant suggesting that not only K application but also straw returning can significantly promote the maize yield. For both wheat and maize, the potassium fertilizer with straw returning had the maximum promoting effects on yield. Comparison analysis demonstrated that the response of maize to the fertilizing mode used in this study was higher than that of wheat. The NPK treatment resulted in an increase by 2.7 kg and 9.7 kg in yield per kilogram K_2O for wheat and maize respectively. The yield per kilogram K_2O was increased by 1.1 kg and 4.6 kg for wheat and maize in the NPSr treatment compared with the NP treatment while the increases of yield by 4.2 kg and 10.3 kg per kilogram K_2O for wheat and maize were obtained by the NPKSr treatment compared with the NP treatment. Wheat and maize showed the same stability with the best steady yield when treated with NPKSr. Furthermore, the minimum annual output variation coefficient of wheat and maize was 9.5% and 17.1% respectively. Through straw returning, the continuity and comprehensiveness of the potassium supply capacity of the soil was improved, and long-term fertilization with straw returning increased the annual yield stability, with the yield coefficients of variation of wheat and maize being 9.5%–11.7% and 17.1%–18.5%, respectively and the stability of wheat yield significantly higher than that of maize.

The effect of long-term fertilization on nutrient contents of wheat and maize

Table 3 showed the average K uptake of crop grain and straw for 17 years. Table 3 showed that different treatments had a significant impact on the K uptake with some characteristics as follows.

Under long-term fertilization, the K absorptive amount was

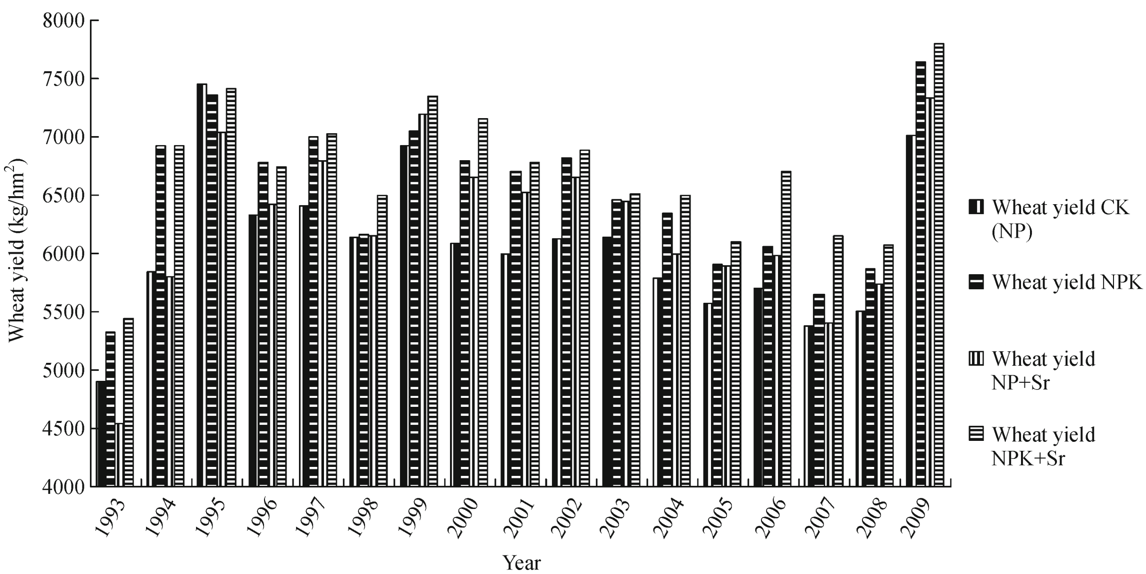

Figure 1 The effect of long-term fertilization on the yield of wheat. 1993–2006 data are from Xing et al. (2010).

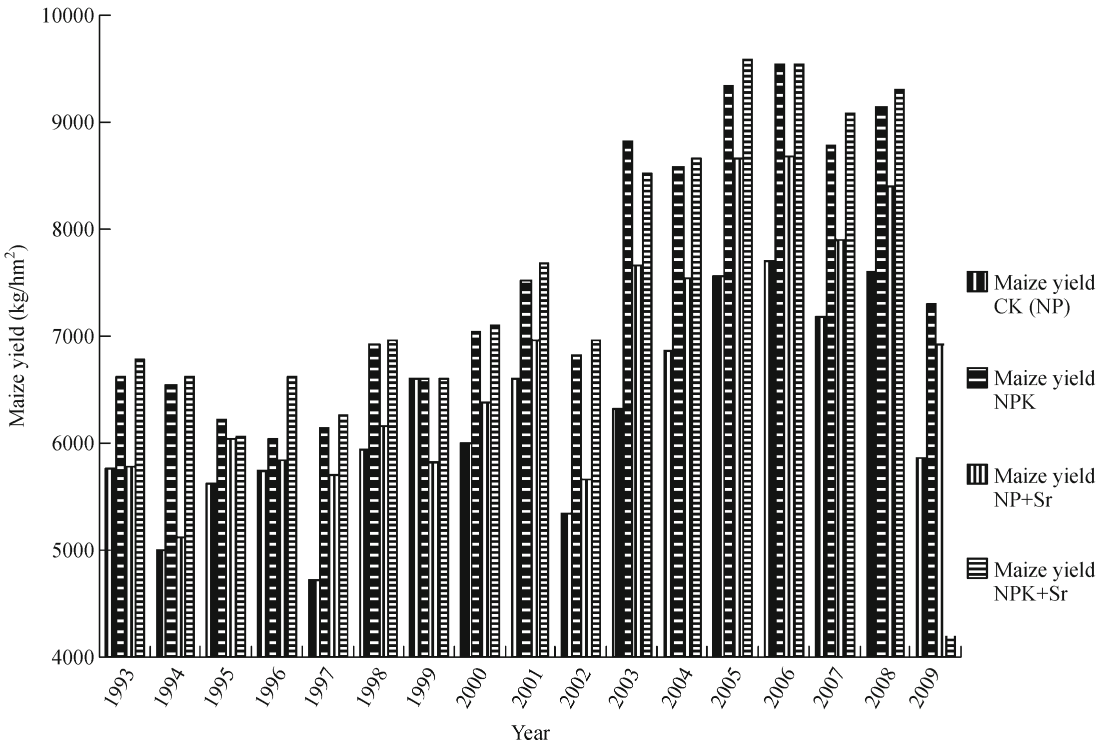

Figure 2 The effect of long-term fertilization on the yield of maize. 1993–2006 data are from Xing et al. (2010).

Table 2 The effect of long-term fertilization on the yield of wheat and maize (average results for 17 years)

Treatment	Yield of wheat	Increased production	Yield of maize grain	Increased production
NP	6048.13±174.12A		6512.64±247.75A	
NPK	6455.94±171.42B	6.74%	7966.33±330.01B	22.32%
NPSr	6219.76±189.80A	2.84%	7204.50±311.39C	10.62%
NPKSr	6673.28±158.05C	10.34%	8063.40±323.69D	23.81%

Data with a different letter within a column are significantly different at 0.01 probability level and 1993–2006 data are from Xing et al. (2010).

Table 3 Effect of straw returning and potassium fertilizer on the K uptake of wheat, maize grain and straw (kg/hm^2, average results for 17 years)

Treatment	K uptake of wheat grain	K uptake of wheat straw	K uptake of maize grain	K uptake of maize straw
NP	29.86±1.46A	75.72±4.16A	24.32±1.38A	47.89±4.41A
NPK	33.84±1.64B	123.58±6.99B	30.99±1.94BC	141.08±15.21B
NPSr	32.18±1.76A	108.55±6.34B	27.50±1.53A	93.62±10.87C
NPKSr	35.64±1.67B	123.12±5.96B	32.37±1.68C	151.10±15.38DB

Data with a different letter within a column are significantly different at 0.01 probability level and 1993–2006 data are from Xing et al. (2008, 2010).

degressive in the sequence of NPKSr > NPSr > NPK > NP. When treated with NP without K fertilizer, the K absorptive levels of maize, wheat grain and straw were the lowest while in the treatment with NPK, the K uptakes of maize, wheat grain and straw were increased to some degree. The highest absorptive amount of K was shown when NPKSr was applied.

A low proportion of K uptake was found in the grains of maize and wheat with little difference between different treatments. However, a high proportion of K uptake was observed in straw, indicating the K absorption was mainly in straw but not in grains.

The K uptake of grain and straw treated with NPK was higher than that with NP, which accounted for 88.24% and 61.28%, and 78.48% and 33.94% of NPK for wheat and maize, respectively, with a higher significant difference.

The K uptake of wheat grain and straw under NP was 92.80% and 69.76% of NPSr, while that of maize was 88.43% and 51.15% of NPSr, without significant difference in grain, but straw.

The K uptake of grain and straw under NP for wheat and maize was 83.79% and 61.50%, and 75.14% and 31.69% of

NPKSr, respectively, indicating significant differences.

In the treatment with NPK, the K uptake accounted for 94.96% and 99.96% of NPKSr and 95.74% and 93.37% of NPKSr for wheat and maize, respectively, which showed no significant difference.

When treated with NPSr, the K uptake of wheat grain and straw was 90.29% and 88.17% of NPKSr, while that of maize was 84.97% and 61.96% of NPKSr, indicating significant differences in the K absorption of wheat grain, maize grain and straw between NPSr and NPKSr treatments.

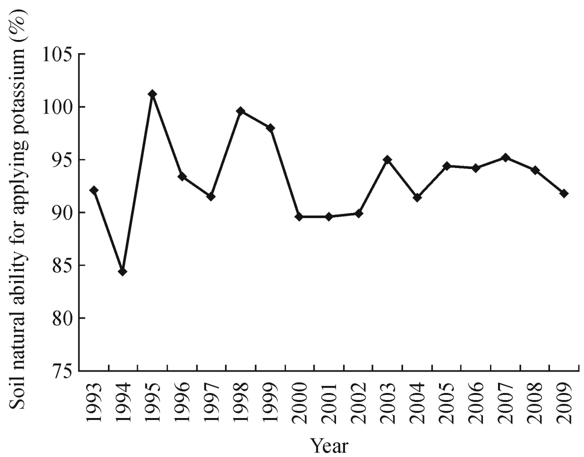

Figure 3 Natural ability for applying fertilizer of wheat in the fluvo-aquic soil area in North China. 1993–2006 data are from Xing et al. (2010).

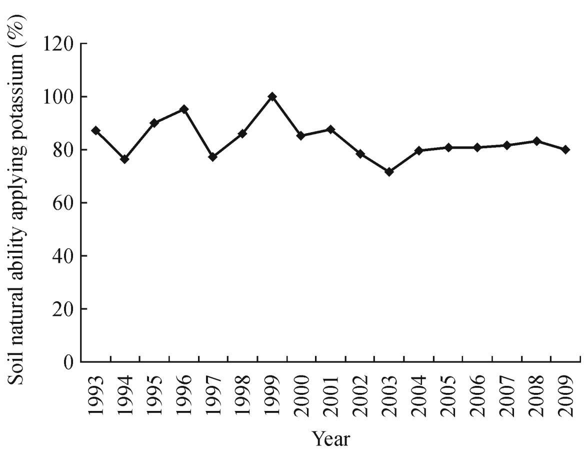

Figure 4 Natural ability for applying fertilizer of maize in the fluvo-aquic soil area in North China. 1993–2006 data are from Xing et al. (2010).

Soil natural ability for applying potassium

Soil natural ability for supplying nutrients refer to that the percentage of crop yield when one nutrient element is absent to the yield with all nutrients presenting. (Lu et al., 1996a, 1996b, 1996c, 1996d, 1996e; Lu, 2000).

This concept established a link between the soil nutrient level and crop yield. Figs. 3, 4 showed the changes of fluvo-aquic soil natural ability for supplying potassium in North China. The average natural ability for supplying potassium of wheat and maize in the north plain of fluvo-aquic soil area was 93.24% and 83.60%.

Besides, it was found that with the experiment time past, soil natural ability for applying potassium of wheat and maize was gradually smooth and steady, showing a slight difference when different crops were planted, such as a stronger deference when wheat was planted than maize.

Discussion

Effects of long-term fertilization on the yields of wheat and maize grain

The results showed that application of K fertilizer and straw returning could significantly increase crop yield in the fluvo-aquic soil area in North China and the yield oeder was NPKSr > NPK > NPSr > NP. The effect of K fertilizer on yield of wheat was less than that on maize, which was consistent with the results of Tan et al. (2008b). The variation coefficient of wheat was smaller than that of maize which was not consistent with Tan et al. (2008b). All of these differences were due to the differences in soil types. K fertilizer application (K_2O 150 kg/hm^2) on the basis of NP fertilizers increased the yields of wheat and maize by more than 6.74% and 22.32%, straw returning increased by 2.84% and 10.62% and the application of the both increased by 10.34% and 23.81%, which was in accordance with Wang's results. The yields of wheat and maize under NPK were 96.74% and 98.80% of NPKSr, with a significant difference. The yield under NPKSr was similar to that under NPK by Li et al. (2006).

In this work, it was revealed that for wheat and maize, 93.68% and 81.75% yield of NPK resulted from NP fertilizers indicating that potash fertilizer had a significant effect on yield increasing. NP fertilizers only brought 97.24% and 90.40% yield of wheat and maize, compared with NPSr that increased 2.84% and 10.62% yield respectively, demonstrating that the straw returning itself increased the yield of maize significantly, but the impact on wheat yield was not significant. For wheat and maize NP fertilizers resulted in 90.63% and 80.77% yield of NPKSr while NPKSr increased 10.34% and 23.81% yield respectively than NP, showing significant difference and the maximum yield effect of K fertilizer with straw returning. Actually, application of K fertilizer was better than straw returning, however, K fertilizer application integrated with straw returning on the basis of NP fertilizers increased the yields of wheat and maize more significantly. From the point of increasing yield by application of 1 kg K_2O, the NPK, NPSr and NPKSr treatments increased yield by 2.7 kg in wheat and 9.7 kg in maize, by 1.1 kg in wheat and 4.6 kg in maize, and by 4.2 kg in wheat and 10.3 kg in maize, respectively higher than NP. Under long-term application of P fertilizer, the application of mere P or NP fertilizers showed a significant increasing yield of wheat and maize. During the 12 years, the yield rate of wheat and maize reached 30.1% and 34.6% compared with FNOP1 and FNOP0 treatments, and 1 kg P_2O_5 increased yield by 9.0 kg in wheat and 18.0 kg in maize (Liu and Zhang, 2000).

The effect of long-term fertilization on nutrient contents of wheat and maize

All the treatments showed soil K deficiency except applying NPK fertilizer with straw returning. The yield was in a order of NPKSr > NPK > NPSr > NP. After 8–10 years, applied potash appeared particularly effective and increased K absorptive capacity of grain and straw by straw returning because the K content in straw was rich, but the K content in grain was only 13%–17% of the total (Tan et al., 2009). Under long-term fertilization, the K absorptive amount was degressive by the sequence of NPKSr > NPSr > NPK > NP. When under the NP treatment, the K absorptive level of maize, wheat grain and straw was the lowest, however, it was increased to some degree when K was integrated with different treatments, with the highest absorptive amount of K under NPKSr. The K absorption in grain and straw was higher when applied with NPK than when applied with NP. The K absorption in grain and straw of wheat and maize under NP accounted for 88.24% and 61.28%, and 78.48% and 33.94% under NPK, while that under NP was 92.80% and 69.76%, and 88.43% and 51.15% under NPSr, respectively. There was no significant difference in the K absorption in grain, but in straw. In terms of NPKSr treatment, the K absorption in grain and straw of wheat and maize under NP was 83.79% and 61.50%, and 75.14% and 31.69% under NPKSr, with significant differences. The K absorption in grain and straw of wheat and maize when treated with NPK was 97.69% and 99.96%, and 95.31% and 94.39% when treated with NPKSr, in which there was no significant difference. Under NPSr treatment, the K absorption in grain and straw of wheat and maize reached 92.98% and 94.49%, and 84.95% and 98.95% under NPKSr respectively, indicating a significant difference between NPSr and NPKSr. The lowest K absorptive amount in grain and plant was 16.8 and 104.3 kg/hm^2 under NP and the highest was 20.8 and 136.0 kg/hm^2 under NPKSr. The sequence of K absorptive amount in grain and plant was NPKSr > NPK > NPSr > NP (Wang et al., 2010).

Soil natural ability for applying potassium

Eleven years of experiments showed that the natural ability of black soil farmland for applying potassium downed to 90% from 100% when without K fertilizer (Wang et al., 2003). Huaibei Vertisol natural ability for applying N, P and K fertilizers was about 20%, 45% and 60%–70% after depletion experiment for 8 years, with 90% natural ability for applying K in the first year without K application downing to 60%–70% in 8 years (Zhan et al., 2006). Moreover, the ability for applying P and K to wheat and maize was different (Liu et al., 2000). In this work, we found that the soil natural ability for applying K was gradually smooth and steady. Different crops had different soil natural ability for supplying K, for example, Soil natural ability for applying potassium was higher when wheat was planted than when maize was planted.

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