Potassium is an important nutrient for cotton; it can increase cotton productivity by increasing number, size, and weight of bolls and improve fiber quality properties such as length, strength, and micronaire (Cassman et al., 1990; Oosterhuis et al., 2013). Additionally, an adequate K supply can increase water use efficiency of cotton and reduce the incidence and severity of pest and disease attacks (Minton and Ebelhar, 1991; Prabhu et al., 2007). Cotton requires 150 to 200 kg K ha\(^{-1}\), as much as nitrogen (N) or even more (Brar et al., 1987; Hodges, 1992; Rochester, 2007). Bolls are the major sink for K, thus the need for K increases at flowering through fruiting (Read et al., 2006; Mullins and Burmester, 2010). And the daily K uptake peaks at 2.2 to 5.0 kg K ha\(^{-1}\) d\(^{-1}\) a few weeks after the start of flowering (Halevy et al., 1987).

Cotton is more sensitive to low soil K than most other major field crops such as soybean \([Glycine max\ (L.)\ Merr.\]
, corn \([Zea mays\ L.\]
, and wheat \([Triticum aestivum\ L.\]
 (Cope, 1981; Kerby and Adams, 1985) because of its less dense root systems, and even K deficiency in cotton can occur in soils not considered low in K (Cassman et
al., 1989). In the last two decades, widespread K deficiencies have been documented throughout several leading cotton producing countries including China (Dong et al., 2004; Tian et al., 2008), India (Sekhon and Singh, 2013), the United States (Oosterhuis, 2001; Coker et al., 2009; Golden, 2014), and Pakistan (Akhtar et al., 2003; Zia-ul-hassan et al., 2014). It has been speculated that these K deficiencies are related to the introduction of high-yielding, early-maturing, and fast-fruiting cotton cultivars (Oosterhuis et al., 1990) as well as the wide use of Bacillus thuringiensis (Bt) cotton since the 1990s (Phipps et al., 2004; Tian et al., 2008; Sekhon and Singh, 2013). In addition, the serious imbalance between N and K fertilizers applications probably led to the K deficiency in cotton. According to the FAOSTAT database and data from the International Fertilizer Association, the K$_2$O/N ratio declined sharply from about 1.0 in the 1940s to 1950s to about 0.28 recently (Magen, 2012). In China, the K$_2$O/N ratio was below 0.2 (Zhang et al., 2010). Therefore, special attention should be given to K management in cotton.

Compared with N, K is retained by soils more strongly and thus less leached; the over application of K fertilizer is tolerable in terms of environmental consequences. However, considering the increasing cost of K fertilizer and the scarcity of proven K reserves in China (Research and Markets, 2011), a sound K fertility program is essential to maximize economic benefit of cotton production.

The NCP, also known as the Huang-Huai-Hai Plain, covering the plains of Beijing and Tianjin Municipalities as well as Hebei, Henan, and Shandong Provinces and the plains in northern Jiangsu and Anhui Provinces, is one of the three major cotton producing areas in China. Fluvo-aquic soil (Calcaric Cambisols, FAO) derived from river sediments is the most cropped soil in this area. The soil is of high fertility and is especially rich in available K (avg. 142.8 mg kg$^{-1}$) (Huang et al., 1999). However, the information from the databases of CNKI (China National Knowledge Infrastructure; http://www.cnki.net/) and Web of Knowledge (http://www.webofknowledge.com/) showed that all the 36 original articles published since 1990 on cotton K management in the NCP reported an increase in cotton yield following the application of K fertilizer. Among these, 16 papers investigated the optimum and maximum K rates for cotton. However, little is known of the effect of K source on cotton yield; furthermore, only two articles paid attention to application timing (Song et al., 1993; Li et al., 2012).

Despite large quantities of K uptake by cotton (Brar et al., 1987; Hodges, 1992; Rochester, 2007), only less than 20% of K was removed by harvested seed and lint (Bassett et al., 1970; Hodges, 1992; Rochester, 2007). Therefore, if cotton stalks, including roots, stems, leaves, and burs, were returned to the field, soil K depletion would be alleviated to a great extent. Recently, cotton-stalk returning has become feasible in China as a result of continuous improvement in related machines and environmental concerns caused by burning of stalks in the field. To our knowledge, however, few studies on K fertilizer involving the effects of recycling stalks have been performed in the NCP.

Our objective was to determine the effects of K source, rate, and timing of application on cotton yield and K use efficiency under conditions of cotton-stalk returning to the field. The results would help cotton growers to optimize K management for yield improvement and economic returns.

**MATERIALS AND METHODS**

The high-yielding commercial cotton cultivar Guoxinmian 3 (containing Bt gene and cowpea trypsin inhibitor [CpTT] gene, developed by Guoxin Cottonseed Company and hereafter referred to as GX3) was used in the present study. Acid-delinted seeds with imidacloprid seed coating of GX3 were provided by Guoxin Cottonseed Company, China.

**Experimental Site**

Field experiments were conducted in Hejian city in Hebei province (38°41′N lat, 116°09′E long, 11 m asl) during 2010 and 2011 growing seasons. The area has a fluvo-aquic soil (Calcaric Cambisols, FAO) with clay loam texture. The soil organic matter, total N, available N, Olsen-P, and exchangeable K in the topsoil (20 cm), determined following the procedures of Bao (2000), were 14.8 and 1.195 g kg$^{-1}$ and 68.7, 10.3, and 169 mg kg$^{-1}$, respectively.

The climate of the site is warm temperate, subhumid, continental monsoon with cold winters and hot summers. The rainfall is variable with greater distribution in July and August. Cotton is usually planted in mid-April and harvested at the end of October. The average air temperature and total precipitation during the growing season (Apr. to Oct.) were 20.7°C and 431 mm in 2010, and 21.2°C and 481 mm in 2011.

**Experiment Design**

Three separate experiments were designed to investigate the effects of K source (Experiment I), rate (Experiment II), and application timing (Experiment III) on lint yield, K uptake, and K use efficiency. Experiment I consisted of a control (no K applied) and two K sources (sulfate of potash, K$_2$SO$_4$, and muriate of potash, KCl) at the same rate of 90 kg K$_2$O ha$^{-1}$, which is used by local cotton growers. Four rates of K fertilizer (0, 45, 90, and 180 kg K$_2$O ha$^{-1}$) were studied in Experiment II with K$_2$SO$_4$ as K source. For Experiments I and II, the K fertilizer was applied in two equal splits: one at preplanting and one at peak bloom. In Experiment III, the K rate of 90 kg K$_2$O ha$^{-1}$ with K$_2$SO$_4$ as source was full dose at preplanting (T1), earlier split applied (one-half at preplanting and one-half at peak squaring, T2; two-fifths at preplanting and three-fifths at peak squaring, T3), later split applied (one-half at preplanting and one-half at peak bloom, T4; two-fifths at preplanting and three-fifths at peak bloom, T5), and with no K application as a control. A randomized complete block design with four replicates was adopted in all three experiments.

Each plot consisted of eight cotton rows 6 m long and spaced 90 cm apart. The planting distance within rows was 21 cm (5.3 plants m$^{-2}$). Cotton was sown on 24 Apr. 2010 and 21 Apr. 2011. At preplanting, 48 kg N ha$^{-1}$ and 138 kg P$_2$O$_5$ ha$^{-1}$ were plowed into the soil. At peak bloom, 138 kg N ha$^{-1}$ was
top dressed. Urea (46% N) and diammonium phosphate (46% P₂O₅, 16% N) were used as N and P sources.

**Field Management**
Cotton stalks were returned to the field for three consecutive years before our experiments. The field was irrigated with 600 to 700 m³ ha⁻¹ water 15 d before planting each year. Soils were then plowed and harrowed when their mellowness was considered physically acceptable. Hill seeding with plastic film mulching was applied. One vigorous plant per stand was retained at the two-leaf stage. Vegetative branches and apex of main stem were removed by hand at peak squaring and 1 wk after peak bloom. Chemical control of insect and weeds were conducted according to local agronomic practices. Cotton stalks, including roots, stems, leaves and burs, were mechanically shredded with a machine (MHC-150, Maihaco Co.) and returned to the field immediately after harvest.

**Data Collection**
Data were collected for lint yield, yield components, and K uptake and distribution.

**Yield and Yield Components**
Each plot was manually harvested three times. Seed cotton (moisture <11%) was ginned on a 10-saw, hand-fed laboratory gin, and lint yield (kg ha⁻¹) as well as lint percentage (lint per seed cotton, w/w) was determined after ginning. The number of bolls per plant and boll weight (moisture <11%) were determined from 10 plants in the central four rows of each plot.

**Potassium Uptake and Distribution**
Ten uniform plants tagged at squaring in each plot were mechanically shredded with a machine (MHC-150, Maihaco Co.) and returned to the field immediately after harvest. All stalk parts (roots, stems, leaves, and burs) and debris were milled with a mill (RT-34, Kong Tsong Precision Technology Co.) and screened through a 0.5-mm sieve. For K determination, ~0.1 g fine powder sample of each stalk partition was soaked in 1.0 M HCl and shaken for 5 h, and about 0.2 g seeds or lint were digested for 1 to 4 h in 70% concentrated H₂SO₄ and 30% H₂O₂ following the procedure outlined in Bao (2000). Extracts were diluted and analyzed for K content using an atomic adsorption spectrophotometer (SpectAA-50/55, Varian). All determinations were performed in duplicates.

**Potassium Use Efficiency**
For this study, K use efficiency was expressed in two ways: agronomic efficiency (AEK, the increased lint yield [kg] over control per unit [kg] of K₂O applied) and apparent recovery efficiency (REK, the percentage of added K₂O that was recovered in the plant biomass at the end of the growing season) according to following equations:

\[
AEK = \frac{LY_i - LY_{ck}}{F_{K_2O}}
\]

\[
REK = \frac{U_i - U_{ck}}{F_{K_2O}}
\]

where \(LY_i\) is the lint yield (kilograms per hectare) of K treatment, \(LY_{ck}\) is the lint yield (kilograms per hectare) of control; \(U_i\) is the K uptake (kilograms K₂O per hectare) of K treatment, \(U_{ck}\) is the K uptake (kilograms K₂O per hectare) of control; \(F_{K_2O}\) is the amount of K₂O applied (kilograms K₂O per hectare) in K treatment.

**Statistical Analysis**
SAS software (version 8.0; SAS Institute, 1999) was used for statistical analysis of variance. The means of treatments were compared using Duncan’s multiple range tests at 5% probability level. Although there were year × K interactions in some traits of three
experiments (Table 1), the effects of K treatments were consistent in 2 yr. Therefore, data were pooled and presented across years.

RESULTS

Effects of Potassium Source on Cotton Lint Yield, Potassium Uptake, and Potassium Use Efficiency

The number of bolls, boll weight, and lint yield were significantly increased 7.6, 10.6, and 17.5% by K$_2$SO$_4$ and, similarly, 4.5, 10.6, and 13.5% by KCl ($P < 0.05$). The two K sources did not differ in yield and yield components (Table 2).

Both K sources significantly enhanced cotton K uptake. Total K accumulation in the plants increased by 19.5% under K$_2$SO$_4$ and 15.3% under KCl. There were no significant differences in stalk and seed K between the two K sources, but the K$_2$SO$_4$ treatment had more K accumulation in lint (Table 3). On average, stalk K accounted for 79% of total K uptake across K treatments. In addition, K$_2$SO$_4$ produced significantly (45%) greater AEK than KCl and showed a greater REK (albeit, insignificant) than the latter (Table 3).

Effects of Potassium Rate on Cotton Lint Yield, Potassium Uptake, and Potassium Use Efficiency

The low K rate of 45 kg K$_2$O ha$^{-1}$ resulted in significantly (19.4%) higher lint yield than the control (no K applied), and there was no further yield response to K fertilization above this rate (Table 4). Both number of bolls and boll weight had a tendency to increase at low K rate.

Potassium fertilization increased K accumulation in cotton plants by 11 to 22%. Total K as well as stalk and lint K increased with each increment in K rate, but there were no significant differences among different K rates (Table 5). The low K rate showed more than twofold increase ($P < 0.05$) in AEK compared with medium and high K rates. Moreover, the low and medium K rates produced similar REK, which were significantly greater than that of high K rate (Table 5).

Effects of Application Timing of Potassium Fertilizer on Cotton Lint Yield, Potassium Uptake, and Potassium Use Efficiency

The application timing of K fertilizer affected cotton yield significantly. The two later split applications at peak bloom (T4 and T5) produced the highest lint yield, which was significantly (11–14%) higher than the control (no K applied) and 5 to 11% higher than the two earlier split applications at peak squaring (T2 and T3) and full dose at preplanting (T1). Both number of bolls and boll weight contributed to the increased yield of T4 and T5 (Table 6).

In accordance with the yield results (Table 6), the total K accumulation of T4 and T5 was significantly (21–24%) higher than the control and 3 to 8% higher than T2, T3,

---

### Table 2. Effects of K source on yield and yield components.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Boll number</th>
<th>Boll weight</th>
<th>Lint percentage</th>
<th>Lint yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
<td>65b†</td>
<td>4.7b</td>
<td>42a</td>
<td>1274b</td>
</tr>
<tr>
<td>K$_2$SO$_4$</td>
<td>70a</td>
<td>5.2a</td>
<td>41a</td>
<td>1497a</td>
</tr>
<tr>
<td>KCl</td>
<td>68ab</td>
<td>5.2a</td>
<td>1446a</td>
<td></td>
</tr>
</tbody>
</table>

† Means in a column followed by different letters are significantly different at $P < 0.05$.

### Table 3. Potassium accumulation, distribution, and utilization in cotton plants as affected by K source.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stalk K</th>
<th>Seed K</th>
<th>Lint K</th>
<th>Total K</th>
<th>AEK†</th>
<th>REK†</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
<td>95b‡</td>
<td>18b</td>
<td>5.1b</td>
<td>118b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K$_2$SO$_4$</td>
<td>110a</td>
<td>24a</td>
<td>7.5a</td>
<td>141a</td>
<td>2.78a</td>
<td>0.26a</td>
</tr>
<tr>
<td>KCl</td>
<td>109a</td>
<td>22a</td>
<td>5.9b</td>
<td>136a</td>
<td>1.92b</td>
<td>0.21a</td>
</tr>
</tbody>
</table>

† AEK, K agronomic efficiency; REK, K apparent recovery efficiency.
‡ Means in a column followed by different letters are significantly different at $P < 0.05$.

### Table 4. Effects of K rate on yield and yield components.

<table>
<thead>
<tr>
<th>K rate</th>
<th>Boll number</th>
<th>Boll weight</th>
<th>Lint percentage</th>
<th>Lint yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>63a†</td>
<td>4.9a</td>
<td>40a</td>
<td>1234b</td>
</tr>
<tr>
<td>45</td>
<td>67a</td>
<td>5.4a</td>
<td>41a</td>
<td>1473a</td>
</tr>
<tr>
<td>90</td>
<td>62a</td>
<td>5.5a</td>
<td>40a</td>
<td>1371ab</td>
</tr>
<tr>
<td>180</td>
<td>65a</td>
<td>5.5a</td>
<td>40a</td>
<td>1429a</td>
</tr>
</tbody>
</table>

† Means in a column followed by different letters are significantly different at $P < 0.05$.

### Table 5. Potassium accumulation, distribution and utilization in cotton plants as affected by K rate.

<table>
<thead>
<tr>
<th>K rate</th>
<th>Stalk K</th>
<th>Seed K</th>
<th>Lint K</th>
<th>Total K</th>
<th>AEK†</th>
<th>REK†</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>93b‡</td>
<td>18b</td>
<td>5.0b</td>
<td>116b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>101ab</td>
<td>21a</td>
<td>6.1a</td>
<td>129ab</td>
<td>5.32a</td>
<td>0.29a</td>
</tr>
<tr>
<td>90</td>
<td>110a</td>
<td>23a</td>
<td>6.4a</td>
<td>138a</td>
<td>1.53b</td>
<td>0.26a</td>
</tr>
<tr>
<td>180</td>
<td>115a</td>
<td>20a</td>
<td>6.6a</td>
<td>142a</td>
<td>1.09b</td>
<td>0.15b</td>
</tr>
</tbody>
</table>

† AEK, K agronomic efficiency; REK, K apparent recovery efficiency.
‡ Means in a column followed by different letters are significantly different at $P < 0.05$.

### Table 6. Effects of application timing of K fertilizer on yield and yield components.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>Boll number</th>
<th>Boll weight</th>
<th>Lint percentage</th>
<th>Lint yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
<td>68a‡</td>
<td>5.0b</td>
<td>41a</td>
<td>1384c</td>
</tr>
<tr>
<td>T1</td>
<td>68a</td>
<td>5.2b</td>
<td>41a</td>
<td>1454b</td>
</tr>
<tr>
<td>T2</td>
<td>67a</td>
<td>5.5a</td>
<td>40a</td>
<td>1469b</td>
</tr>
<tr>
<td>T3</td>
<td>64a</td>
<td>5.7a</td>
<td>39a</td>
<td>1422b</td>
</tr>
<tr>
<td>T4</td>
<td>69a</td>
<td>5.6a</td>
<td>41a</td>
<td>1578a</td>
</tr>
<tr>
<td>T5</td>
<td>70a</td>
<td>5.5a</td>
<td>40a</td>
<td>1537a</td>
</tr>
</tbody>
</table>

† CK, control (no K applied); T1, full dose at preplanting; T2, 1/2 preplanting + 1/2 peak squaring; T3, 2/5 preplanting + 3/5 peak squaring; T4, 1/2 preplanting + 1/2 peak bloom; T5, 2/5 preplanting + 3/5 peak bloom.
‡ Means in a column followed by different letters are significantly different at $P < 0.05$. 

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and T1. The differences among treatments in stalk and seed K were similar to those in total K (Table 7). Because of the higher yield and greater K uptake, the later split applications (T4 and T5) resulted in significantly (35–103%) higher AEK and 23 to 58% higher REK than the earlier split applications (T2 and T3) and full dose at preplanting (T1) (Table 7).

In addition, almost no significant differences in lint yield, K uptake, and K use efficiency were observed between different ratios of split applied K (one-half vs. two-thirds) whether at peak squaring (T2 vs. T3) or at peak bloom (T4 vs. T5).

### DISCUSSION

#### Optimal Potassium Source for Cotton Production

The most common sources of soil-applied K are KCl and K₂SO₄. The K fertilizer is chosen according to its price and anion type. Because the chloride (Cl⁻) content is below 2.5%, K₂SO₄ is generally used for Cl⁻-sensitive crops such as tobacco (*Nicotiana tabacum* L.), fruits, and some vegetables. Cotton is tolerant to Cl⁻ after seedling establishment (Weir et al., 1996) and can grow and develop normally with 100 to 1600 mg kg⁻¹ of Cl⁻ in soil (Tang and Sheng, 1993). Moreover, Cl⁻ is not adsorbed or held back by soils; therefore, it moves readily with the soil-water from either irrigation or rainfall (Maas, 1984). In a long-term survey executed on many experimental sites in Israel (Hauzengerger, 1965), it was found that winter rain of ~450 mm is sufficient to leach the summer load of Cl⁻ built up by irrigation and fertilization.

In the present study, K₂SO₄ produced an insignificant 3.5% more lint yield than KCl. Pervez et al. (2005) also reported an only 5% increase in yield with the addition of K₂SO₄ relative to KCl. The positive influence of K₂SO₄ on K use efficiency compared with KCl is probably a result of its accompanying anion, SO₄²⁻. However, KCl is much cheaper than K₂SO₄. The unit price of KCl is only one-half to two-thirds that of K₂SO₄ (www.fert.cn, Nov. 2014). Given its lower price and comparable effect on yield, we suggest KCl as the preferred source of K fertilizer for cotton production in the NCP. Nevertheless, it should not be used as starter K in cotton field (Kafkafi et al., 2001) because cotton is sensitive to higher soil Cl⁻ (exceeding 200 mg kg⁻¹) during seeding establishment (Tang and Sheng, 1993).

#### Optimal Potassium Application Rate with Return of Cotton Stalk to the Field

Some researchers (Pettigrew et al., 1996; Mullins et al., 1999; Pervez et al., 2005) reported that K fertilizer ranging from 50 to 200 kg K₂O ha⁻¹ significantly increased cotton lint yield. In contrast, other researchers (Miley et al., 1969; Varco et al., 1994) did not find increase of lint yield when K ranging from 50 to 300 kg K₂O ha⁻¹ was applied. From the 16 papers published since 1990 on K rate in cotton fields in the NCP, a wide range of either optimum K rate (90–225 kg K₂O ha⁻¹) or maximum rate (135–300 kg K₂O ha⁻¹) was reported. The reason for these wide variations is that the yield response of cotton to K nutrient vary with target yield, type and texture of soil, level of soil available K, and agronomic practices.

Soil colloids and the surface of soil clay minerals are negatively charged, thus, K⁺ will tend to be attracted to them. Vermiculitic soils are well known for their K fixation capabilities (Essington et al., 2002). Unruh et al. (1993) also noted that soils containing K-bearing mica have a tendency to fix K. For these types of soils, considerable quantity of K would be needed to overcome fixation before it is made available to plants (Kerby and Adams, 1985). In terms of soil texture, K deficiencies are the most common on coarse (sandy)- and medium (loam)-textured soils that are subject to nutrient leaching. In the present study, soil available K was about 169 mg kg⁻¹. Nevertheless, cotton lint yield still showed positive responses to K fertilizer in all three experiments (Table 2, 4, 6). It is in agreement with the results of nearly all original articles (33 of 36, published since 1990) focusing on K management of cotton in the NCP. Because fluvo-aquic soil has high vermiculite and mica contents (Tan et al., 2012), and the soil texture in our study is clay loam rather than sandy loam, we suggest that the positive effects of K fertilizer on cotton yield were mainly related to the high capability of fluvo-aquic soil to fix K (Essington et al., 2002; Zhang et al., 2009) rather than the leaching of K from topsoil.

When the data in 16 original papers investigating K rate for cotton production in the NCP were compared and analyzed, it was found that the optimum K rates were 100 to 225, 90 to 225, and 90 to 135 kg K₂O ha⁻¹ at <100, 100 to 150, and >150 mg kg⁻¹ of soil available K, respectively, and the corresponding maximum K rates were 220 to 300, 144 to 225, and 135 to 180 kg K₂O ha⁻¹. However, only 45

---

**Table 7. Potassium accumulation, distribution, and utilization in cotton plants as affected by application timing of K fertilizer.**

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>Stalk K</th>
<th>Seed K</th>
<th>Lint K</th>
<th>Total K</th>
<th>AEK‡</th>
<th>REK‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
<td>89b</td>
<td>19b</td>
<td>4.9c</td>
<td>112b</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>T1</td>
<td>104a</td>
<td>21ab</td>
<td>6.6a</td>
<td>132ab</td>
<td>2.04c</td>
<td>0.22b</td>
</tr>
<tr>
<td>T2</td>
<td>102a</td>
<td>22ab</td>
<td>6.8a</td>
<td>130ab</td>
<td>2.20b</td>
<td>0.20b</td>
</tr>
<tr>
<td>T3</td>
<td>103a</td>
<td>22ab</td>
<td>5.2b</td>
<td>129ab</td>
<td>1.68c</td>
<td>0.19b</td>
</tr>
<tr>
<td>T4</td>
<td>107a</td>
<td>23a</td>
<td>6.1a</td>
<td>136a</td>
<td>3.41a</td>
<td>0.27a</td>
</tr>
<tr>
<td>T5</td>
<td>108a</td>
<td>24a</td>
<td>7.1a</td>
<td>139a</td>
<td>2.96a</td>
<td>0.30a</td>
</tr>
</tbody>
</table>

†CK, control (no K applied); T1, full dose at preplanting; T2, 1/2 preplanting + 1/2 peak squaring; T3, 2/5 preplanting + 3/5 peak squaring; T4, 1/2 preplanting + 1/2 peak bloom; T5, 2/5 preplanting + 3/5 peak bloom.

‡ AEK: K agronomic efficiency; REK: K apparent recovery efficiency.

§ Means in a column followed by different letters are significantly different at P < 0.05.
kg K₂O ha⁻¹ increased cotton yield significantly in the present study, with a comparable soil available K at 169 mg kg⁻¹. This possibly resulted from the three consecutive years of cotton stalk returning to the field in advance. In support of this deduction, Li (2014) recently reported that soil available K increased by ~20% after 2 or 3 yr of continuous cotton-stalk retention in Shandong Province of the NCP.

**Optimal Timing of Potassium Application for Cotton Production in the North China Plain**

Potassium in soils is less leached than N. Therefore, K fertilizer is most often applied preplanting. However, the results of many experiments have demonstrated that split application of K fertilizer is essential for cotton production, which is associated with either the K uptake pattern of cotton or soil capacity to fix K and risk of K leaching from topsoil.

The need of cotton for K rises dramatically when the boll load begins to develop (Halevy, 1976), and approximately two-thirds of the total K uptake occurs during a 6-wk period beginning at early flowering (Reddy et al., 2000). However, cotton root growth slows during boll development, making it unable to meet the K requirements of aboveground parts. This also explains why K deficiency in cotton can occur in soils not considered low in K (Cassman et al., 1989). Therefore, the preplanting K application may not always be sufficient for cotton production; the last split application should be done before first bloom (Hake et al., 1996).

Moreover, split application can be a good practice in light-textured soils because K may be leached. In other cases, split application of K fertilizer may be recommended in soils with high K-fixing capacity even when soil K tests show a high range (Manzoor et al., 2008; Zörb et al., 2014). In the present study, when K fertilizer was split-applied at peak bloom (T4 and T5), higher lint yield as well as greater AEK and REK were obtained (Tables 6, 7). This was likely attributed to the stronger capacity of fluvo-aquic soil to fix K.

**CONCLUSIONS**

Despite the slightly increased lint yield under K₂SO₄ and its greater K use efficiency, considering the lower price of KCl and the tolerance of cotton to Cl⁻ after seeding establishment, KCl should be the preferred source of K fertilizer for cotton production in the NCP. Under conditions of returning cotton stalk to the field with high soil available K above 150 mg kg⁻¹, the low K rate of 45 kg K₂O ha⁻¹ (relative to the reported levels of 90–135 kg K₂O ha⁻¹ in the NCP) is adequate for cotton production. In addition, the later split application of K at peak bloom had higher lint yield and K use efficiency than the earlier split application at peak squaring and full dose at preplanting, and is therefore the best timing of K fertilizer for cotton in the NCP.

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