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Spatial distribution of potassium uptake across the cotton plant affects fiber length

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ABSTRACT

To enhance whole plant fiber quality of cotton, the relationship between the spatial distribution of potassium (K) absorption and fiber length was investigated. In 2007, a field experiment was conducted to assess genotypic differences among 17 cultivars for potassium absorption and fiber length. Differences in both K uptake and fiber length existed among cultivars in field conditions. The cultivars could be categorized into three classes: moderate K uptake and high fiber length; high K uptake and moderate fiber length; and both low K uptake fiber length. In 2008, single cultivars representative of each of these three classes were selected to further investigate spatial distribution patterns of K absorption and cotton fiber length, respectively. In 2009, differences among the three selected cultivars in K uptake and fiber length were further studied under three K fertilizer regimes and by foliar spraying of KCl. Higher K uptake at upper and distal positions of the plant was associated with longer fiber; however, at lower and proximal positions no such association was observed. The change of K uptake and fiber length is related to cultivar and K fertilizer application as well. For all three cultivars, without K fertilizer application, K uptake and fiber length decreased from lower to upper sections and from proximal to distal positions. With increasing K application, K uptake increased for all positions, especially upper and distal positions. For cultivar Siza3, higher fiber lengths were consistent with greater K uptake at upper and distal sections. For cultivar Xuza3, fiber length declined markedly when K application rate increased from 225 to 450 kg hm^{-1} even if K absorption was enhanced. For Sumian9, fiber lengths were no longer increased when K rate increased from 225 to 450 kg hm^{-1}. These results suggested that rational K fertilizer management could improve whole plant fiber length of cotton cultivars that have intermediate K absorption potential with high uptake ability at upper and distal positions.

1. Introduction

Cotton fiber length is important for the textile industry. Both fiber length and uniformity are key indices of fiber quality (Foulk et al., 2009; Robert et al., 2010; Xiong et al., 2013). However, fiber length differs between different positions of cotton plants, and the difference is related to both growth environment and mineral nutrition levels. Potassium (K) plays an important role in fiber length (Pettigrew et al., 1996; Pettigrew, 2003), because K affects electrical potential gradients of cell membranes, turgor generation, anion–cation balances, enzyme activation, protein synthesis, photosynthetic production and many other physiological processes (Bednarz et al., 1998; Zhao et al., 2001; Dong et al., 2005). The occurrence of K deficiency in cotton has increased across the cotton production regions in the world, contributing to chlorophyll degradation, reduced photosynthesis in mature leaves, and premature senescence as common growth limiting features (Zhang et al., 2009; Bo et al., 2012). Abnormal growth results in reduced lint yield and fiber length.

K deficiency in cotton relates to both genotype and inadequate K supply (Zhang et al., 2007; Pettigrew et al., 1996; Pettigrew, 2003). Several studies have focused on finding high potassium use efficiency germplasm resources (George et al., 2002; Yang et al., 2003; Pettersson and Jensen, 1983). Jiang et al. (2003) studied genotypic

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differences in potassium use efficiency of 83 cotton cultivars, and screened for cultivars that tolerated low K supply. Genotypes showing high K efficiency usually have greater uptake or use efficiency (Rengel and Damon, 2008; Keino et al., 1996). Wang et al. (2012) indicated that highly K efficient genotypes usually have larger root systems and greater internal K use efficiency.

Many studies were also conducted about use of K fertilizer to fulfill the nutrient balance demand in cotton. Gomus and Yucel (2002) suggested that K deficiency exists during the rapid boll set period because the requirement for K exceeds the ability of soil and leaves to supply K. Tian et al. (2008) reported that K deficiency is correlated with root growth in cotton. However, these studies focused mainly on impacts of K deficiency and K fertilizer application level on yield and fiber quality; less is known about the relationship of fiber quality with increased or decreased K uptake in different parts of the cotton plant (Cassman et al., 1989, 1990; Xi et al., 1989).

Cotton plant size is usually large in the Yangtze River Region, where cultural practices favor low plant density and high fertilizer rate (Chen, 2005; Li, 2008). Under these conditions, cotton plants have about 20 fruiting branches, and five to six fruiting nodes per fruiting branch. The upper and external positions of the plant are key contributors to lint yield and quality. The quantity and quality of retained bolls on these position is highly correlated with K supply (Gomus and Youcel, 2002; John et al., 2008). Fiber length, as the main indicator of fiber quality, shows significant differences at different sections of the cotton plant (Liu et al., 2006). However, there has been little study of how K impacts fiber length at different plant sections, especially the upper and external sections. Therefore, our objectives are to investigate: (a) whether genotypic differences exist for K uptake and fiber length among cotton cultivars, (b) the relationship between spatial distribution of K absorption and fiber length for different sections of the cotton plant, and (c) the effect of K supply on spatial distribution of K absorption and cotton fiber length.

2. Materials and methods

2.1. Field experiment

The experiments were conducted on the farm of Yangzhou University (32°30′N, 119°25′E) in 2007–2009. In 2007, 17 cultivars (all with long fruiting cycles) from the main cotton breeding units of China were selected to assess potassium absorption and fiber length differences among cotton genotypes. The 17 cultivars were planted with potassium (K) application rate of 300 kg ha^{-1} KCl. The soil contained 2.17 g kg^{-1} organic matter, and available N, P and K at 110.2, 38.6, and 76.3 mg g kg^{-1}, respectively. Seeds were first planted in a warm room covered by plastic mulch on April 6, then seedlings were transplanted to the field at 40 days after sowing (DAS40, May 17) at spacing of 0.90 × 0.32 m^2. Nitrogen and phosphorus fertilizer application rates, soil moisture supply and other production measures were conducted according to local farm management practices. The experiment was arranged in a randomized complete block design with three replications. The plot dimension was 10 × 5.4 m^2.

Based on 2007 experimental results, a field experiment was conducted in 2008 among three cultivars with different K absorption rates and fiber lengths, to investigate the characteristics of K absorption and fiber length at different positions of the cotton plant. The soil contained 2.15 g kg^{-1} organic matter, and available N, P and K at 108.5, 35.2, and 75.5 mg g kg^{-1}, respectively. Fertilizer application rates (nitrogen, phosphorus and potassium) were all the same as in the 2007 experiment. Enough soil moisture (70–80% of field capacity) was provided during the cotton growth season. Three cultivars were selected based on the 2007 experiment results as entries. The experiment was again arranged in a randomized complete block design with three replications, with plot dimensions and other field management practices the same as in 2007.

In 2009, two more field experiments were conducted among the same three cultivars to further investigate the spatial distribution of K absorption and fiber length at different K fertilizer application levels, and how fiber length is affected by direct K spraying on the subtending leaf of different sections. Soil N, P and K content was similar to those in 2007 and 2008. In experiment 1, a split-plot design with three replications was used, with the three cultivars as main plots and K fertilizer treatments as sub-plots, totaling 27 plots with the same planting pattern and plot sizes as in 2007 and 2008. Three K fertilizer rates, CK (0 kg hm^{-2}), mid-K (225 kg hm^{-2}), and high-K (450 kg hm^{-2}) of KCl (56% K_2O) were applied. In experiment 2, a split-plot design with three replications was used, with cultivars as main plots and K foliar spraying treatments as sub-plots. The labeled subtending leaves and flowers from the upper and lower positions of the plant were sprayed at the second day after flowering with 20 mg g^{-1} KCl or water, respectively, and then further sprayed every fifth day from 21 August to 5 September (i.e., a total of three times). In addition to the K nutrient treatments, suitable nitrogen, phosphorus, and enough soil moisture were applied during the cotton growth season (as in 2007 and 2008 experiments). Other management practices were also consistent with local farm management.

The daily minimum and mean temperatures were above 15 °C and 20 °C, respectively, during the cotton fiber elongation phase of the three-year experiments at Yangzhou University Farm, and therefore could not restrict fiber elongation of upper and distal bolls.

2.2. Preparation of samples

2.2.1. Determination of biological yield

In all experiments from 2007 to 2009, ten representative plants from the fifth row of each plot were selected to determine biological yield. These plants were uprooted at maturity (30% of bolls opened), and separated into base, middle and upper sections according to the average number of fruiting branches. Each section was separated into proximal (the three fruiting positions nearest the main stem for each fruiting branch) and distal (beyond the third fruiting position) parts. The roots, stems and branches, leaves, boll walls, seeds and lint of each section were separated for drying. Dry matter was weighted and recorded after drying at 80 °C to constant weight. Plant debris was also collected near sampled plants between rows weekly, and dried immediately. Biological yield was determined from the total dry weight of all organs plus the collected debris.

2.2.2. Assay of K nutrient uptake

The dry tissue samples were ground using a cyclone mill, passed through an 80 mm sieve, then 0.5 g aliquots from each sample were moist-ashed with H_2SO_4-H_2O_2. The K concentration of the sample was determined by flame photometry. The K uptake and accumulation were estimated as follows:

$$\text{Kuptake} = \text{Kconcentration} \times \text{drymatterweight}$$

2.2.3. Lint yield

Plants from the second, third, and fourth rows of each plot were manually harvested four times. Seed cotton was ginned after drying (moisture ≤11%), then weighed by plot to determine lint yield.

2.2.4. Fiber length

At the second and third rows of each plot, 30 bolls developed from labeled flowers were harvested from different sections of