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Plant growth regulation enhanced potassium uptake and use efficiency in cotton

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ABSTRACT

The effects of plant growth regulators (PGRs) and potassium (K) fertilizer on cotton (*Gossypium hirsutum*) yield have been well documented but the role of PGRs on K use efficiency is poorly understood. Our specific objective was to determine whether foliar application of PGRs could improve K use efficiency in field-grown cotton. Field experiments were conducted with or without K at two sites (Beijing and Hebei, China) varying in available soil K during 2010 and 2011, with cotton cvs. Guoxinmian3 (GX3) and SCRC28 as test materials. Foliar application of the PGRs, mepiquat chloride (MC) and Miantaijin [MTJ, a combination of MC with diethyl aminoethyl hexanoate (DA-6)] during squaring and flowering periods significantly increased the lint yield and K uptake in most situations at Beijing location and had a consistent tendency to increase lint yield across K fertilizers and years at Hebei location. The partial factor productivity (PFPK) and agronomic efficiency of K (AEK) were enhanced by the application of the PGRs in most situations in Beijing, especially in 2011 and for the cultivar GX3. Although differences in the apparent recovery efficiency of K (REK) between PGRs and control were not significant, a positive and consistent effectiveness of PGRs on REK was observed across sites, years and cultivars. Therefore, the application of PGRs would be a useful practice for improving K nutrition and lowering the cost of K fertilizer input in cotton production.

1. Introduction

Potassium (K) is a major macronutrient in plants, involved in many essential processes, such as osmoregulation and cell extension, stomatal regulation, activation of enzymes, protein synthesis, photosynthesis, and phloem loading (Marschner, 1995; Pettigrew, 2008). It also improves crop physical quality, disease resistance, and product quality (Harris, 1997; Oosterhuis et al., 2013). However, the application of K to agricultural fields worldwide is much lower than nitrogen (N). According to the FAOSTAT database and data from the International Fertilizer Association (IFA), the K_2O/N ratio declined sharply from about 1.0 in the 1940–1950s to about 0.28 recently (Magen, 2012). Although the consumption of K fertilizers in China has increased rapidly in recent years, the K_2O/N ratio is still below 0.2 (calculated from the data in Fig. 1, Zhang et al., 2010). This nutrient imbalance has resulted in the continual depletion of soil K (Ladha et al., 2003; Wang et al., 2007) and frequent K deficiency (Dobermann et al., 1998). A county-wide study in Hebei province (North China Plain) found that soil available K decreased by 51.3 and 70.3 mg kg^{-1} from 1980 to 1999 in rainfed and irrigated lands (Kong et al., 2006).

Cotton (*Gossypium hirsutum*) is an important fiber crop in the world, and about 4 million hectares are grown annually in China (Dong et al., 2006). Cotton requires a larger amount of K and appears to be more sensitive to K deficiency in soils than other crops (Cassman et al., 1989). Potassium deficiency can impair the growth and development of cotton plants (Pettigrew and Meredith, 1997; Reddy et al., 2000; Zhao et al., 2001), result in premature senescence and leafspot disease (Gulick et al., 1989; Oosterhuis, 1994; Harris, 1997), reduce the yield potential and decrease the fiber quality (Bennett et al., 1965; Cassman et al., 1990; Minton and Ebelhar, 1991; Pettigrew et al., 1996). With the

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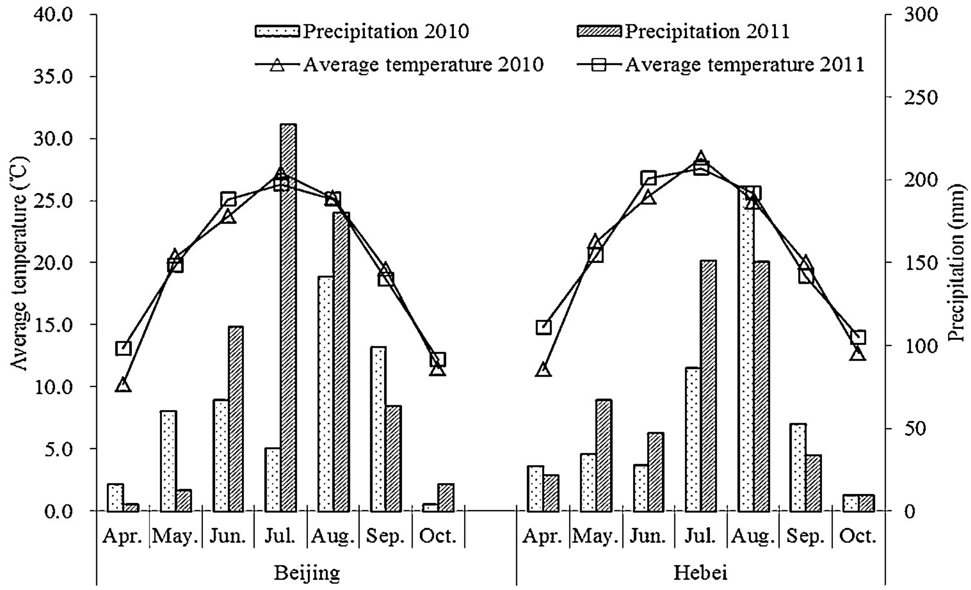

Fig. 1. Monthly weather summary during the cotton growing season in Beijing and Hebei from 2010 to 2011.

adoption of modern cotton cultivars characterized by faster fruit set and greater boll load (Oosterhuis, 1999) and popularization of transgenic Bt (*Bacillus thuringiensis* Berliner) cotton, which is more susceptible to K deficiency (Zhang et al., 2007; Tian et al., 2008; Yang et al., 2011), K deficiency in cotton fields has become more frequent (Oosterhuis, 1994; Tian et al., 2008).

The distribution of proven K reserves in the world is seriously skewed with China having only 2.2%, making it highly dependent on import of potash fertilizer (Research and Markets, 2011). On the other hand, the apparent recovery efficiency of K (REK, calculated as the ratio between the amount of fertilizer K removed with the crop and the amount of fertilizer K applied) in China is only 21–36%, being lower than in developed countries (Zhang et al., 2008). Therefore, improving the K use efficiency is a worthy goal and fundamental challenge.

Exogenous application of plant growth regulators (PGRs) is a well-recognized strategy to increase the yield, improve quality and alleviate stress-induced adverse effects on crop production (Dashora and Jain, 1994; Akram and Ashraf, 2013). Furthermore, there are some evidences that PGRs can regulate the uptake and accumulation of mineral nutrients in plants. For example, gibberellin acid (GA_3), ethylene (ETH) and abscisic acid (ABA) stimulated the K uptake of winter wheat (Erdei and Dhakal, 1988). Clark et al. (1992) reported that foliar application of PGR-IV [0.0028% gibberellin acid (GA_3) + 0.0030% indolebutyric acid (IBA)] could increase the uptake of K, phosphorus (P), calcium (Ca) and iron (Fe) in cotton plants. An impressive increase in N uptake and recovery efficiency of mustard (*Brassica juncea*) in response to ethrel application was reported in Mir (2002). The study of Khan et al. (2005) demonstrated that GA_3-treated plants had a two-fold increase in sulphur (S) recovery efficiency in mustard.

The plant growth regulator, mepiquat chloride (MC, 1,1-dimethylpiperidinium chloride) is a gibberellin inhibitor. It has been used worldwide to suppress excessive growth in cotton plants by decreasing plant height, number of nodes, fruiting and vegetative branch lengths, and leaf area and to hasten maturity and avoid yield losses (He and Yang, 1983; Krieg and Kerby, 1985; He et al., 1988; Hodges et al., 1991; Reddy et al., 1992; Rademacher, 2000; Ren et al., 2013). In China, the application of MC has covered about 80% of cotton fields since the 1990s (He et al., 1995; Mao and Yan, 2005). Apart from plant canopy manipulation, MC can enhance root growth by increasing the number of lateral roots (Li, 1990; Tang, 1992), increase root vigor by increasing the reducibility and respiratory rate (unpublished data) and thereby increase the uptake of N, P and K (Jin et al., 1984; He et al., 1988, 1990, 1991). Diethyl aminoethyl hexanoate (DA-6) is also one plant growth regulator used to stimulate growth (Yokoyama et al., 1982; Zhang et al., 2003). Miantaijin (MTJ) is a combination of 25% MC and 2.5% DA-6, developed by China Agricultural University and registered in 2009 by Fujian HaoLun Biological Engineering Technology Co., Ltd. The results of field experiments in Yellow River valley and Yangze River valley cotton growing region indicated that MTJ not only could control the excessive vegetative growth of cotton plants effectively as MC did, but also could increase the lint yield and enhance the root vigor of cotton (Tian et al., 2006b; Fan et al., 2008; Du et al., 2012; Xu et al., 2013). Therefore, it has been successfully applied in part of cotton fields in China.

Despite several important studies on MC and MTJ involving cotton, their effects on K use efficiency have been seldom studied up to now. Thus, we determined the effects of foliar application of MC and MTJ on K use efficiency in cotton to confirm our hypothesis that PGRs may enhance K uptake and K use efficiency in cotton plants.

2. Materials and methods

2.1. Locations and materials

Field experiments were conducted during 2010 and 2011 growing season at Shangzhuang experimental station of China Agricultural University with a sandy loam soil in Beijing (40°08′ N, 116°10′ E, Elev. 51 m; hereafter referred to as Beijing) and Hejian city with a clay loam soil in Hebei province (38°41′ N, 116°09′ E, Elev. 11 m; hereafter referred to as Hebei). Soil organic matter, total N, available N, Olsen-P, exchangeable K and pH of topsoil (20 cm) were determined following procedures of Bao (2000), and presented in Table 1.

The climate of both sites is warm-temperate and 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 monthly average air temperature and rainfall duration during the growing season (2010–2011) are presented in Fig. 1.

Two high-yielding commercial cotton cultivars, Guoxinmian 3 [containing *Bt* gene and cowpea trypsin inhibitor (*CpTI*) gene,