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RELATIONSHIP AMONG ROOT CHARACTERISTICS AND DIFFERENTIAL POTASSIUM UPTAKE AND USE EFFICIENCY OF SELECTED COTTON GENOTYPES UNDER POTASSIUM DEFICIENCY STRESS

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Abstract

Potassium (K) uptake and K use efficiency are the most important characters of plant genotypes that determine their biomass production under K deficiency stress. This study reports the influence of some important root characters on the K uptake and use efficiency of three pre-selected cotton genotypes under K deficiency stress. These genotypes included CIM-506, NIAB-78 and NIBGE-2, selected on the basis of their differential K use efficiency i.e., low, medium and high, respectively. Cotton genotypes significantly ($p<0.01$) differed for their K use efficiency, K uptake of shoot, root and on total basis, tap-root length, lateral root number and specific K absorption rate based on tap root length. While, K accumulation rate, K translocation efficiency, K transport rate and specific K absorption rate based on root dry weight were non-significant. The genotype NIBGE-2 was the most tolerant genotype to K deficiency stress and performed best for all the parameters studied followed by NIAB-78 and CIM-506. A significant correlation was observed between K use efficiency and K uptake of cotton genotypes. The root characteristics viz., tap root length, lateral root number, K accumulation rate and specific K absorption rate directly influence both K uptake and use efficiency of cotton under deficient K condition. K translocation rate and specific K absorption rate, based on root dry weight, directly influence total K uptake but not K use efficiency. These physio-morphological root traits of cotton are highly important while breeding for K-use-efficient cotton genotypes.

Introduction

Potassium (K) is an important nutrient for plant growth and development due to its versatile role in plant physiology and biochemistry. K deficient soils prevail all over the world (Rengel & Damon, 2008) because K-fertilization is highly unaffordable (Zia-ul-hassan & Arshad, 2008). Hence, crop production on K-deficient soils is an emerging challenge to modern agriculture and there is a dire need to device strategies for low-K-input agriculture. Nutrient-use-efficient genotypes possess great potential to sustain yield under nutrient deficient environment (Rengel & Damon, 2008) through enhanced uptake and efficient utilization of deficient nutrients (Zia-ul-hassan & Arshad, 2010). Differential K uptake and utilization efficiency have been identified among various crop species and their genotypes (Nawaz *et al*., 2006; Zia-ul-hassan & Arshad, 2008; 2010). The differential K uptake among species have been attributed to the differential influx at plasmalemma (Pettersson, 1978), gene-controlled carrier synthesis (Jensen & Pettersson, 1978) and K status of plant and culture media (Pettersson & Jenson, 1978). Later on, Glass *et al*., (1981) elucidated that the K (Rb^+) uptake in barley strongly correlated with H^+ efflux from its roots. In tomatoes, it was observed that K use efficiency is controlled by K utilization too, in addition to K uptake and translocation (Makmur *et al*., 1978). Nawaz *et al*., (2006) reported strong correlation between root dry biomass and K uptake and K use efficiency of maize genotypes. Root characteristics appeared to be the most important factor determining K uptake and its translocation to rice shoots under K deficient condition (Jia *et al*., 2008). Since K is a diffusion-supplied nutrient, root morphology plays an important role in K uptake and K use efficiency (Nawaz *et al*., 2006; Rengel & Damon, 2008). Due to the less prolific root system of cotton (Dong *et al*., 2004), higher K uptake rates and greater K accumulation are both attributed to K-efficient cotton cultivars (Cassman *et al*., 1989). Moreover, the efficiency of K utilization between genotypes have been attributed to variation in K translocation capacity at a cellular and whole plant level, as K is highly mobile in plants (Rengel & Damon, 2008).

Root plays an important role in soil-plant system (Lynch *et al*., 2007) because of the direct relationship between root and shoot growth (Jia *et al*., 2008). Effective root morphology and efficient root distribution pattern are the fundamental mechanisms of nutrient acquisition from deficient environments (Lynch *et al*., 2007; Rengel & Marschner, 2005). The relationship between root morphology and K nutrition of various crop species viz., pea, red clover, lucerne, barley, rye, perennial ryegrass and oilseed rape has been documented (Høgh-Jensen & Pedersen, 2003). Crops maintain K uptake by modifying their root hair length under K deficient conditions (Jia *et al*., 2008). For the improvement of mineral nutrition traits, involving K in breeding programs, K uptake efficiency, K influx, K translocation and K use efficiency should be given consideration (Pettersson & Jenson, 1983). This study reports the influence of some important root characters on the K uptake and use efficiency of three preselected cotton genotypes under K deficiency stress.

Materials and Methods

The experiment involved three preselected cotton genotypes viz., CIM-506, NIAB-78 and NIBGE-2, having low, medium and high K use efficiency, respectively, under K deficiency stress (Zia-ul-hassan & Arshad, 2010). The experiment was conducted in a glass house under natural conditions. Sand germinated, one-week old, uniform sized seedlings of three cotton genotypes were carefully transplanted to foam plugged holes made on 1.5 L black-paint-coated plastic jars, filled with one-half strength K-deficient (0.3 mM) Johnson's solution (Johnson *et al*., 1957). The pH of nutrient solution was maintained every second day around 5.5. Plants were harvested after 28 (H1) and 40 days (H2) of transplanting, thoroughly washed and blotted dry. The dry weights of shoots and roots were recorded. Plant samples were digested using diacid mixture of nitric acid and perchloric acid (Miller, 1998) to determine K concentration on a Jenway PFP Flame Photometer. K use efficiency was the shoot dry weight per shoot K concentration, as described by Siddiqi & Glass (1981). K uptake by a plant part was calculated by multiplying its K concentration and dry weight. Tap root length was measured by using a measuring tape. The lateral root numbers were counted by spreading the roots on a white paper sheet. Specific K absorption rate of a genotype was calculated either based on root dry weight (SARW) or tap root length (SARL), using the formula given by Hunt (1978). Accordingly, SARW/SARL = [(Total K uptake H2 − Total K uptake H1) ÷ (RDW/TRL H2 − RDW/TRL H1)] × [(ln RDW/TRL H2 − ln RDW/TRL H1) ÷ (T2 − T1)]. K accumulation rate (KAR) was calculated as described by Elliot & Lauchli (1985) i.e., KAR = (ln Shoot K uptake H2 − ln Shoot K uptake H1) ÷ (T2 − T1). K transport rate (KTR) was calculated by using the formula given by Pitman (1972) i.e., KTR = [(Shoot K uptake H2 − Shoot K uptake H1) ÷ (SDW H2 − SDW H1)] × [(ln SDW H2 − ln SDW H1) ÷ (T2 − T1)]. K translocation efficiency (KTE) was the shoot K uptake per total K uptake. The experiment was repeated twice in a completely randomized fashion involving four plastic jars of each genotype, each having three plants. The jars were placed on an iron table over white thermopore sheets by randomizing the genotypes within each replication. Rotation of jars was performed on alternate days to provide homogenous environment. The data obtained from the two experiments were pooled for the analysis of variance using Statistix for Windows ver. 8.1 (Analytical software© 1985-2005) and the means were separated by Tukey's honestly significant difference at alpha 0.05.

Results

The differential behavior of cotton genotypes was observed for their K use efficiency and K uptake (shoot, root and total) when grown under K deficiency stress, as the F-ratio for genotypes from analysis of variance (ANOVA) were highly significant ($p<0.01$). Among the parameters studied for their influence on K use efficiency and K uptake, the F-ratio from ANOVA was significant ($p<0.01$) for tap root length, lateral root number and specific absorption rate calculated on root length basis, while non-significant for K accumulation rate, K translocation efficiency, K transport rate and specific absorption rate calculated on root dry weight basis. Both the tap root length and lateral root number of NIBGE-2 were significantly more than CIM-506 and NIAB-78 (Fig. 1). The tap root length and lateral root number of NIBGE-2 were 8% and 19% more than NAIB-78, respectively, while 13% and 34% more than CIM-506, respectively. Moreover, NIAB-78 had 5% and 13% more tap root length and lateral root number than CIM-506, respectively. The root shoot ratio of NIBGE-2 was also 8% more than NIAB-78 and 13% more than CIM-506 (data not shown). Consequently, both the K uptake (Fig. 2) and K use efficiency (Fig. 3) of NIBGE-2 were significantly more than other two genotypes. All genotypes significantly differed for K uptake by their shoot, root and on total basis (Fig. 2). The shoot, root and total K uptake of NIBGE-2 was 60%, 81% and 62% more than NIAB-78, while 239%, 271% and 233% more than CIM-506, respectively. Whereas, shoot, root and total K uptake of NIAB-78 was 112%, 106% and 105% more than CIM-506, respectively. Cotton genotypes also greatly differed for their K use efficiency (Fig. 3). The K use efficiency of NIBGE-2 was 100% and 240% more than NIAB-78 and NIBGE-2, while NIAB-78 had 112% more K use efficiency than CIM-506. The specific K absorption rate on root weight basis (SARW) of all cotton genotypes was statistically alike (data not shown), nonetheless, NIAB-78 had 11% and 52% more SARW than NIBGE-2 and CIM-506. The cotton genotype NIBGE-2 had 37% more SARW than CIM-506. Contrarily, specific K absorption rate on root length basis (SARL) of all cotton genotypes differed significantly (Fig. 4). Again NIBGE-2 had maximum SARL that was 54% and 225% more than NIAB-78 and CIM-506, respectively. The genotype NAIB-78 had 111% more SARL than CIM-506. The cotton genotypes behaved alike for their K translocation efficiency, K translocation rate and K absorption rate (data not shown). Though negligible, K translocation efficiency of NIBGE-2 and NIAB-78 was greater than CIM-506. However, K transport rate and K accumulation rate of NIBGE-2 was 7% and 33% more than NIAB-78, respectively, while 38% and 44% more than CIM-506, respectively. Moreover, NIAB-78 had also 29% and 8% more K transport rate and K accumulation rate than CIM-506, respectively. The correlation analysis was performed to study the relationship of various plant characters with K use efficiency and K uptake. A significant correlation ($p<0.01$) existed between K use efficiency and K uptake of cotton genotypes. The K use efficiency had highly significant correlation ($p<0.01$) with tap root length, lateral root number and specific K absorption rate on root length basis. However, comparatively weak ($p<0.05$) relationship was observed between K use efficiency and K accumulation rate. Similarly, K uptake had highly significant correlation with tap root length, lateral root number and specific K absorption rate on root length basis. However, comparatively weak relationship ($p<0.05$) of K uptake was found with K accumulation rate, K transport rate and specific K absorption rate on root weight basis. A non-significant relationship of K translocation efficiency was noted both with the K use efficiency and total K uptake. Likewise, both the K transport rate and specific K absorption rate on root weight basis had non-significant relationships with the K use efficiency.

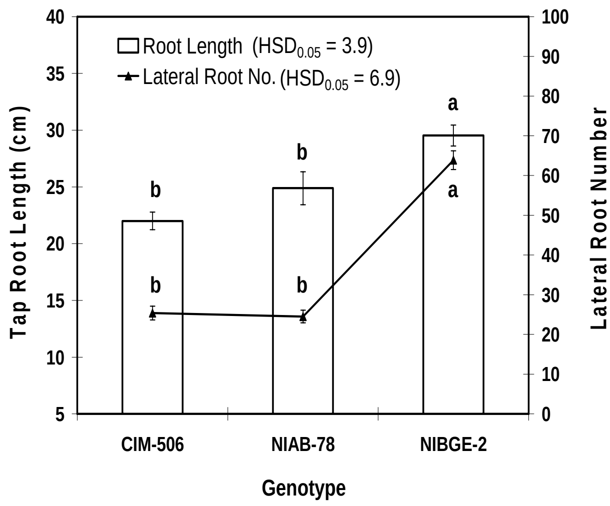

Fig. 1. Tap root length and lateral root numbers of differentially K-use-efficient cotton genotypes under K deficiency stress.

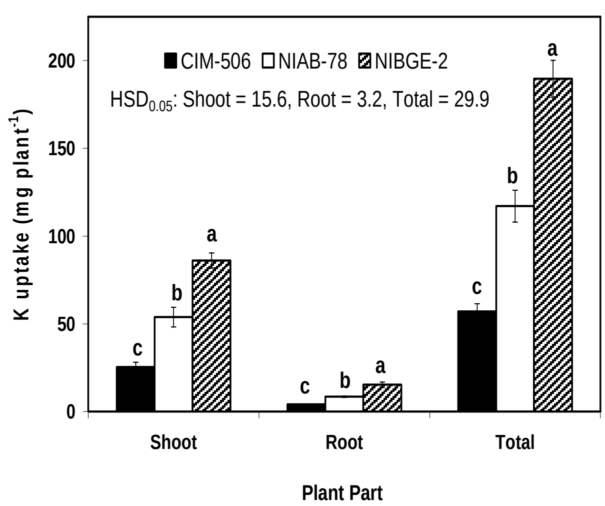

Fig. 2. K uptake of differentially K-use-efficient cotton genotypes under K deficiency stress.

Discussion

Nutrient-use-efficient crop genotypes possess great potential to perform well under limited nutrient environments (Rengel & Damon, 2008; Zia-ul-hassan & Arshad, 2008; Zia-ul-hassan & Arshad, 2010) by way of efficient acquisition and best utilization of nutrients from their deficient environments (Sattelmacher *et al*., 1994). Our results also demonstrated considerable differences among cotton genotypes for K use efficiency and K uptake under K deficiency stress. K utilization efficiency had significant positive correlation with K uptake, concluding that an integration of these two most important plant characters could be used for selection of cotton genotypes better adapted to low K conditions. Sattelmacher *et al*., (1994) also found positive correlation between K use efficiency and K uptake of wheat genotypes and advocated this approach for the selection of nutrient efficient crop genotypes. They elucidated that some peculiar physiological mechanisms enable nutrient use efficient genotypes to acquire adequate amounts of a certain nutrient (uptake efficiency) and/or to utilize that amounts more efficiently (utilization efficiency). Nutrient use efficiency studies involve the measures of the ability of plants to obtain nutrients. Specific absorption rate is the rate of nutrient uptake per unit root dry weight (SARW) or root length (SARL) or the index of root uptake efficiency (Hunt, 1978). In this study, cotton genotypes behaved alike for their SARW but significantly differed for their SARL. This indicated that cotton root length is more important in acquiring more K from its deficient conditions than root dry weight. Indeed, cotton has less prolific root system and hence root length plays more significant role in acquiring K from remote rhizosphere pockets than root weight (Dong *et al*., 2004). Earlier too, it has been reported that crops maintain K uptake by modifying their root hair length under K deficient conditions (Jia *et al*., 2008). In the present study, despite non-significant differences among genotypes for K translocation efficiency, K transport rate and K accumulation rate, NIBGE-2 relatively had higher values for these parameters than CIM-506 and NIAB-78. Consequently, NIBGE-2 had maximum K uptake and K use efficiency. The K transport rate suggested by Pitman (1972) is related to shoot K concentration and shoot growth rate at two growth stages, while K accumulation rate described by Elliot & Lauchli (1985) describes the ability of a plant to obtain, particularly retain, some amount of nutrient in a given time. Plants with good absorption ability per unit time generally have higher accumulation rate. Genotypes with higher nutrient transport rate are able to translocate more of that nutrient from their roots to their shoots than genotypes with low nutrient transport rate. Genotypes with low ability to translocate a nutrient from root to shoot are less tolerant to the deficiency of that nutrient because they are less efficient to absorb that nutrient from growth medium and partly because they have a lower ability to translocate that nutrient from roots to shoots. Enhanced K uptake is a very important plant character of efficient cotton genotypes due to their less prolific root system. Diffusion - the typical mechanism supplying K to plant roots – is severely affected under low K conditions, due to low K diffusion coefficient (Dong *et al*., 2004). Hence, under K deficiency stress, efficient root system plays an important role in cotton tolerance to K deficiency stress (Brouder & Cassman, 1990; Dong *et al*., 2004; Rengel & Damon, 2008). These findings are supported by the results of the present study elucidating that the efficient cotton genotype NIBGE-2 had significantly more tap root length, lateral root number and specific K absorption rate based on root length. The statistically non-significant differences among three cotton genotypes for their K translocation efficiency, K transport rate and K accumulation rate also revealed that the previously mentioned root characters were mainly responsible for enhanced K uptake of cotton genotypes under K deficiency stress. Earlier studies also reported direct influence of root growth on shoot growth (Nawaz *et al*., 2006; Lynch *et al*., 2007) due to the vital role of an efficient root system in enhanced K acquisition from K deficient environments (Rengel & Marschner, 2005; Rengel & Damon, 2008; Zia-ul-hassan & Arshad, 2008;

Ali *et al.*, 2010). There exists strong relationship between root morphology and K nutrition of crop species, as reported by Høgh-Jensen & Pedersen (2003) for pea, red clover, lucerne, barley, rye, perennial ryegrass and oilseed rape. Crops modify their root hair length under varying K levels and hence efficient genotypes potentially tolerate K deficiency through enhanced K uptake from its sparingly soluble sources (Jia *et al.*, 2008). The root morphology attributes of K-inefficient rice genotypes decreased more than efficient genotypes under K deficient condition (Jia *et al.*, 2008; Jabeen and Ahmad, 2009). It is concluded that under potassium deficiency stress, the root traits of cotton viz., tap root length, lateral root number, K accumulation rate and specific K absorption rate directly influence both K uptake and use efficiency. K translocation rate and specific K absorption rate, based on root dry weight, directly influence total K uptake but not K use efficiency. These important physio-morphological root traits of cotton are highly important while breeding for K-use-efficient cotton genotypes.

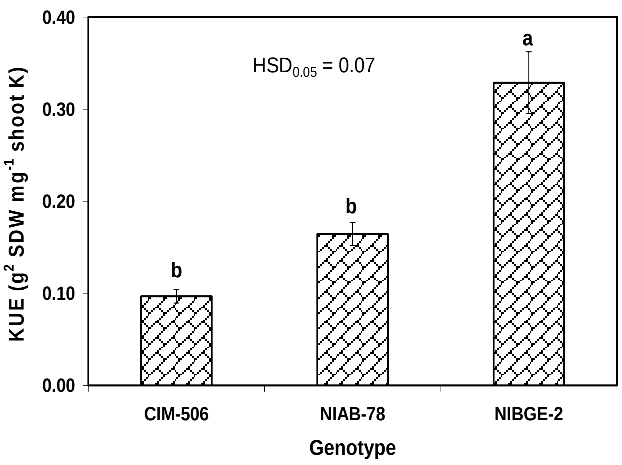

Fig. 3. K use efficiency (KUE) of differentially K-use-efficient cotton genotypes under K deficiency stress.

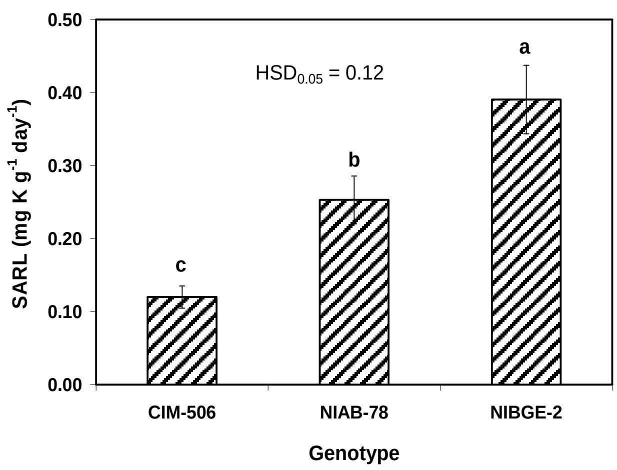

Fig. 4. Specific absorption rate of differentially K-use-efficient cotton genotypes calculated on the basis of root length (SARL) under K deficiency stress.

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