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.

**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 planted in a glass house under natural conditions.
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 SDW H2 − ln RDW/TRL H2) − (ln SDW H1 − ln RDW/TRL H1)] × [(ln SDW H2 − ln SDW H1) − (T2 − T1)]. K translocation efficiency was calculated by using the formula given by Pittman (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, K transport rate and 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 length 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.

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 highly significant (p<0.01) for tap root length, lateral root number and specific K 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 NIAB-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.
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, 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. 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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.

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