Exploiting Genotypic Variability among Cotton Cultivars for Potassium Use Efficiency

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Abstract

Crop responses to potassium in Pakistan are sporadic. Furthermore farmers are reluctant to use K fertilizer, depleting K in soil. Cultivation of efficient K-utilization genotypes may be a promising alternate strategy. Therefore, an experiment was conducted in the greenhouse of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad to study the differential growth response and K-utilization efficiency among cotton genotypes. We evaluated growth response and potassium utilization efficiency of 7 cotton cultivars grown under adequate (3.0 mM) and deficient (0.3 mM) K supply in hydroponics. Cultivars were grown for 4-5 weeks to study growth physiological parameters relating tolerance against K deficiency. Cultivars differed significantly in biomass production, shoot K concentration, uptake and use efficiency at both levels of K supply. Shoot and root biomass production was significantly decreased due to K deficiency stress. Reduction in shoot dry matter varied significantly among cultivars and efficient cultivars showed minimum reduction in shoot dry matter due to K deficiency. The result indicated significant genetic differences in K utilization efficiency among cotton cultivars which can be exploited for breeding efficient cultivars to be grown under low K soils especially in low input sustainable agriculture

Keywords: Cotton, potassium, genetic variations, nutrient use efficiency

Introduction

The economy of Pakistan is dependent on agriculture, and soil being the basic raw material for agriculture has prime importance in this respect. Cotton is the main cash crop and contributes significantly to the national economy. Pakistan is the fourth largest producer of cotton in the world and third largest exporter of raw cotton. Cotton and cotton products contribute about 10 percent to GDP and 53 percent to the foreign exchange earnings of the country (GOP, 2011-12).

Potassium deserves special attention in cotton production because of high uptake rate and less inefficient K uptake mechanism compared to many other crops (Kerby and Adams, 1985). The cotton plant is more complex structurally than any other major field crop. Cotton, with its indeterminate growth habit, produces vegetative and reproductive growth simultaneously over a relatively long period (130-180 days). The indeterminate growth characteristics of the cotton plant means that K needs to be adequate to meet the simultaneous requirement for vegetative growth and boll development (lint and seed). This can be expected to place considerable demand on the available K supply at certain stages of growth (Pettigrew, 1999). Cotton yield suffers more often from inadequate K fertilization than soybean, corn and wheat crops (Cope, 1981).

The exploitation of genotypic differences by selecting and identifying crop genotypes best adapted to the adverse soils with nutrients is one of the key strategies for the sustainable intensification of agricultural systems (Baligar *et al.*, 2001; Yang, 2003). With regard to genotypic differences among crop varieties for potassium use efficiency, research has been conducted involving a number of crops viz rice (Sabir *et al.*, 2003; Gill *et al.*, 2002; Yang *et al.,* 2003) maize (Farina *et al.*, 1983) , Wheat (Gill *et al.*, 1995,1997) and Sugarbeet (Marschner *et al.*, 1981). Genotypic differences among cotton cultivars were also found in relation to absorption and utilization of nitrogen (Pettigrew et al., 1996) Phosphorus (Gill and Ahmad, 2003) potassium (Cassman *et al.*, 1989; Gill *et al.,* 1997).

These results invites our attention to identify the genotypes with higher potassium use efficiency and understand the mechanism of differences in response to applied potassium, in order to future breeding of high nutrient efficient genotypes.

Materials and Methods

A solution culture experiment was carried out in the rain protected wire house of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, during the year 2005.Seeds of seven cotton genotypes, viz. CIM-473, CIM-506, CIM-707, CIM-496, CIM-499, NIAB-824 and NIAB-884 were collected from various Agricultural Research Institutes of Punjab .The germination of seeds were achieved in plastic tubs (28″x14″x12″) containing washed sand .Distilled water was sprinkled over these tubs to maintain optimum moisture contents for seed germination and seedling establishment.

Ten days after sowing uniform sized seedlings were transplanted in foam plugged holes of thermopal sheets floating on continuously aerated 100 L ½ strength modified Johnsons's solution (Johnson *et al.* 1957) in polyethylene lined iron tubs (1m x 0.5m x 0.3m). Twenty eight plants were maintained in each tub by randomly repeating four plants of each cultivar in equally spaced numbered holes. Moreover, each plant was properly tagged also. One tub was kept as control, containing solution with adequate level of K (3.00 mM). In another tub, the solution was modified to contain deficient level of K (0.3 mM). Both the tubs were supplied with adequate concentration of other nutrients. The pH of nutrient solution was maintained at 5.5±0.2 (Mahmood, 1999; Fageria, 2005) using H_2SO_4 and/or $Ca\ (OH)_2$ (Mahmood, 1999). The experiment was laid out in completely randomized factorial design with four repeats (one plant per repeat).

Harvestings was done after 4-5 weeks of transplanting. Harvested plants were washed with distilled water and dried with the help of blotting paper. Roots and shoots were separated at harvesting and were immediately put in the paper bags before air drying in the laboratory. Later, they were dried at 70°C for 48 hours in an oven and the oven dry weights were recorded. Growth parameters i.e. root dry matter, shoot dry matter and root: shoot ratio was determined while potassium concentration in digested plants was estimated by taking 0.5 g shoot or root sample and was digested in 10 mL diacid mixture of nitric acid and perchloric acid with a ratio of 3:1. Potassium concentration (Kc) (mg g^{-1}) of shoot and root was determined on a flame photometer (Jenway PFP-7).

Results and Discussions

Shoot Dry Matter

General plant health can be guessed on the basis of a number of growth parameters. Amongst different parameters shoot dry matter is considered the most sensitive plant response parameter to nutrient deficiency and is given a pivotal place in screening experiments (Fageria *et al.*, 1997).

Table 1a showed that there were significant differences in SDM production due to K-levels and variety x K level interaction and non significant due to varieties. Shoot dry matter production of different cotton varaities at both adequate (3 mM K) and deficient (0.3 mMK) levels is shown in the table 1.At the adequate K level, shoot dry matter production ranged from 7.23 g plant^{-1} (CIM-506) to 2.51 g plant^{-1} (NIAB-884). At deficient K level, SDM yield of cotton varieties ranged from 3.52 g plant^{-1} (NIAB-884) to 0.94 g plant^{-1} (CIM-506) to 0.94 g plant^{-1}. The genotype CIM-506 produced the maximum SDM; followed by CIM-707.while the NIAB-884 produced the minimum SDM at adequate level of potassium. It can be postulated that the varieties showed the genetic variability for SDM production at both adequate and deficient levels of potassium.

Genetic differences for SDM production were also reported by Mahmood *et al.* (2001) and Gill *et al.*, (1997) in wheat, Cassman *et al.* (1989) in cotton., Sabir *et al.* (2003) in rice and *Gill et al.* (2005) in chickpea.

Root Dry Matter

Nutrient uptake capacity of a plant is directly correlated with its root weight. Increased root dry matter production may be a good indicator of enhanced root surface area for absorption of K from growth medium.

Data regarding root dry matter (RDM) production by seven cotton varieties presented in Table 1. The statistical analysis of variance (Table 1b) showed that there were significant difference in RDM production due to K level and K level and variety interaction, however the non significant differences due to varieties. At adequate K level RDM production ranged from 0.44 g plant^{-1} (CIM-506) to 0.11 g plant^{-1} (NIAB-884). At deficient K level NIAB-884 genotype produced the maximum RDM (0.36 g/plant), which was significantly different from other six varieties. There was a decrease in RDM of all the varieties as the potassium concentration decreased from 3 mMK to 0.3 mMK in growth medium.

Sabir *et al.* (2003) in rice, Mahmood *et al.* (2001) and Gill *et al.* (1997) in wheat genotypes and Gill *et al.* (2005) in chickpea reported genetic differences with respect to root dry matter.

Root Shoot Ratio

Root: shoot ratio is a measure of relative distribution of dry matter between root and shoot of the plant. Data regarding root shoot ratio is presented in table 1. Statistical analysis of data (Table 1c) showed a non-significant effect due to varieties and variety x level interaction but significant due to K levels.

Root shoot ratio increased 1-3 folds at deficient K level as compared to adequate K level, which may be attributed to low SDM accumulation at deficient K level, rather than due to increased RDM. Generally plants tend to accumulate more K in roots when grown under nutrient deficient condition. This increase in photosynthetic accumulation results in an increase of RSR of plants. (Table 1) showed that at the deficient K level root shoot ratio ranged between 0.14 and 0.05. CIM-473 exhibited the lowest RSR while the highest RSR was exhibited by NIAB-824. At the adequate K level CIM-506 had maximum RSR (0.06) while the NIAB-884 had the minimum RSR (0.04), but no variety was superior in terms of RSR production at the adequate or at the deficient K levels.

Genetic differences for root shoot ratio were also reported by Martin *et al.* (1997) in sorghum , Gill *et al.* (1997) and Mahmood *et al.* (2001)in wheat , Sabir *et al.* (2003) in rice and Gill *et al.* (2005) in chickpea.

Table 1: Growth performance of seven cotton cultivars at adequate and deficient level of K supply.

Cultivars	Shoot dry matter (g)		Root dry matter (g)		Root : shoot	
	Adequate K	Deficient K	Adequate K	Deficient K	Adequate K	Deficient K
CIM-496	3.71 bc	1.41 b-d	0.2.0 bc	0.11 c	0.06 ^{NS}	0.09 ^{NS}
CIM-707	7.09 a	1.19 cd	0.345 ab	0.10 c	0.05	0.11
CIM-506	7.23 a	0.94 d	0.44 a	0.06 c	0.06	0.10
CIM-496	3.25 b-d	1.76 b-d	0.16 c	0.14 c	0.05	0.09
CIM-473	3.81 b	1.22 cd	0.20 bc	0.04 c	0.05	0.05
NIAB-824	3.87 b	2.39 b-d	0.20 bc	0.14 c	0.05	0.14
NIAB-884	2.51 b-d	3.52 bc	0.11 c	0.36 ab	0.04	0.12
K Level Mean	4.50 A	1.78 B	0.24 A	0.14 B	0.05 B	0.10 A

Means followed by the same letter(s) in each column are statistically non significant at 5% probability

Table 1a. Analysis of variance for shoot dry matter of cotton varieties as affected by K levels

S.O.V	Df	SS	MS	F Value
K Level (L)	1	103.692	103.692	43.7219 **
Variety (V)	6	24.393	4.066	1.7142 ^{NS}
L xV	6	80.079	13.347	5.6276 **
Error	42	99.608	2.372	
Total	55	307.772		

Table 1b. Analysis of variance for root dry matter (g plant^{-1}) of cotton varieties as affected by K levels

S.O.V	Df	SS	MS	F Value
K Level (L)	1	0.139	0.139	12.6086**
Variety (V)	6	0.107	0.018	1.6120 ^{NS}
L xV	6	0.454	0.076	6.8615 **
Error	42	0.463	0.011	
Total	55	1.163		

Table 1c. Analysis of variance for root: shoot ratio of cotton varieties as affected by K levels

S.O.V	Df	SS	MS	F Value
K Level (L)	1	0.034	0.034	10.1195**
Variety (V)	6	0.009	0.001	0.4426 ^{NS}
L xV	6	0.011	0.002	0.5648 ^{NS}
Error	42	0.141	0.003	
Total	55	0.195		

Shoot Potassium concentration

Shoot concentration of plant indicates the efficiency of a plant to take up K from the growth medium (Ashraf *et al.*, 1997). Statistical analysis of data (table 2a) showed a significant influence of K level and non significant influence of a variety and variety x K level on shoot potassium concentration. Table 2 showed that potassium concentration in shoot of cotton varieties at deficient and adequate level of potassium. At adequate K level, NIAB-884 showed the maximum K concentration (66.32 mg g^{-1}) while the CIM-707 had the minimum K concentration in shoot. Genotypes NIAB-824, CIM-473, CIM-499, CIM-506 and CIM-496 were found to be statistically similar. At deficient K level shoot potassium concentration ranged from 40.44 mgg^{-1} to 23.04 mg g^{-1}, but the differences were non significant. Average over all genotypes K concentration in shoots of cotton genotypes decreases 2 folds due to K deficiency.

Genetic differences in terms of K concentration were also reported by Ashraf *et al.* (1997), George *et al.* (2002), Yang *et al.* (2003), Sabir *et al.* (2003) and Gill *et al.* (2005) in different crops.

Potassium Utilization Efficiency

Here the term "utilization" describes the conversion of primary resources (CO_2, H_2O and inorganic nutrients) into biomass at given nutrient concentration of the plant tissue. Potassium utilization efficiency is a measure of biomass production per unit of tissue potassium concentration. This parameter can be helpful in identifying plant genotypes that can yield better under low concentration of a particular nutrient (Siddiqui and

Glass, 1987). Analysis of variance (Table 2b) revealed a non-significant influence due to K level and variety while a significant influence due to variety x level interactive on potassium utilization efficiency.

At adequate K level (Table 2), CIM-707 showed the maximum potassium utilization efficiency (0.17 g^2/mg K) followed by CIM-506 (0.13 g^2/mg K) while the NIAB-884 showed the minimum KUE (0.04 g^2/mg K). At the deficient K level NIAB-884 showed the maximum KUE (0.12 g^2/mg K). Genotypes NIAB-824, CIM-473, CIM-499 and CIM-496 were found to be statistically similar in KUE.

Genetic differences for KUE were also reported by Gill *et al.* (1997), Mahmood *et al.* (2001) and Zhang *et al.* (2004) in wheat, Cassman *et al.* (1989) in cotton genotypes and Chen and Gableman (1995) in tomato.

Potassium Uptake

Potassium uptake is the amount of K that is actually taken up by the plant in producing SDM at particular growth stage. Statistical analysis of data (Table 2c) showed a significant difference in potassium uptake due to K-level, variety x K level interaction and non-significant due to variety. Potassium uptake of cotton varieties grown in adequate (3 mMK) and deficient (0.3 mMK) levels of potassium is represented in table 2. AT adequate K level, CIM-506 showed the maximum K uptake (413.40 mg plant^{-1}) followed by CIM-707 while CIM-499 showed the lowest K uptake (157.55 40 mg plant^{-1}). At deficient K level potassium uptake varied from 122.01 40 mg plant^{-1} (NIAB-884) to 25.06 40 mg plant^{-1} (CIM-473).

It can be postulated that varieties showed the genetic variability for potassium uptake at adequate and deficient levels of potassium. Averaged over the seven varieties 5 fold decreases in K uptake was observed as K concentration in the growth medium decreased from 3.0 mMK to 0.3 mMK.

Maschner *et al.* (1981), Sabir *et al.* (2003) and Gill *et al.* (2005) reported genetic differences with respect to K uptake in cotton, rice and chickpea respectively.

Table 2: Potassium concentration, uptake and utilization efficiency of maize cultivars grown at adequate and deficient K levels

Cultivar	Shoot K conc. (mg g^{-1})		KUE (g^2 mg^{-1} of K)		Shoot K Uptake (mg g^{-1})	
	AdequateK	DeficientK	AdequateK	DeficientK	AdequateK	DeficientK
CIM-496	57.36 ab	31.01 ^{NS}	0.07 bc	0.06 bc	209.17 bc	41.31 de
CIM-707	43.62 b	30.41	0.17 a	0.04 c	326.54 ab	35.86 de
CIM-506	56.50 ab	31.73	0.13 ab	0.03 c	413.40 a	28.13 e
CIM-499	48.20 ab	23.04	0.07 bc	0.08 bc	157.55 c-e	44.31 de
CIM-473	49.20 ab	25.10	0.09 a-c	0.08 bc	197.74 b-d	25.06 e
NIAB-824	48.01 ab	40.44	0.08 bc	0.07 bc	188.54 b-e	82.27 c-e
NIAB-884	66.32 a	35.14	0.04 c	0.12 a-c	174.84 b-e	122.01 c-e
K Level Mean	52.74 A	30.98 B	0.09 A	0.07 B	238.26 A	54.14 B

Means followed by the same letter(s) in each column are statistically non significant at 5% probability

Table 2a. Analysis of variance for shoot potassium concentration of cotton varieties as affected by K levels

S.O.V	df	SS	MS	F Value
K Level (L)	1	6630.272	6630.272	35.8644 **
Variety (V)	6	1434.075	239.012	1.2929 ^{NS}
L xV	6	821.541	136.924	0.7406 ^{NS}
Error	42	7764.561	184.870	
Total	55	16650.448		

Table 2b. Analysis of variance for potassium utilization efficiency of cotton varieties as affected by K levels

S.O.V	Df	SS	MS	F Value
K Level (L)	1	0.008	0.008	2.8099 ^{NS}
Variety (V)	6	0.008	0.001	0.4990 ^{NS}
L xV	6	0.060	0.010	3.5181 **
Error	42	0.119	0.003	
Total	55	0.195		

Table 2c. Analysis of variance for Potassium uptake of cotton varieties as affected by K levels

S.O.V	Df	SS	MS	F Value
K Level (L)	1	474600.609	474600.609	48.9763 **
Variety (V)	6	84846.042	14141.007	1.4593 ^{NS}
L xV	6	161062.319	26843.720	2.7701 *
Error	42	406997.063	9690.406	
Total	55	1127506.033		

Potassium Utilization Index (%):

Siddiqui and Glass (1987) proposed that nutrient utilization index is a parameter, which defines or estimates the plasticity of a cultivar or specie to adapt to a nutrient deficient environment. Potassium utilization index indicates the relative decrease in the KUE as the potassium concentration in the growth medium is decreased from adequate to deficient level. Statistically analysis of data (Table 3a) indicated the significant difference among the varieties for PUI. Data regarding PUI (Table 3) revealed that NIAB-884 showed the maximum PUI (4.30%) value, therefore seemed to have higher plasticity in adapting to a K stress environment. Genotypes NIAB-824, CIM-473, CIM-499, CIM-496, CIM-707 and CIM-506 were found to be statistically similar in PUI.

Clark *et al.* (1983) in wheat and Sabir *et al.* (2003) in rice genotypes obtained similar results.

Table 3. Potassium utilization index (%) of cotton varieties

Varieties	KUI (%)
CIM-496	0.94 b
CIM-707	0.35 b
CIM-506	0.42 b
CIM-499	1.23 b
CIM-473	1.01 b
NIAB-824	1.03 b
NIAB-884	4.30 a
Total within	1.32

Means followed by the same letter(s) in each column are statistically non significant at 5% probability

Table 3a. Analysis of variance for potassium utilization index (%) of cotton varieties as affected by K levels

S.O.V	Df	SS	MS	F Value
Between(V)	6	44.087	7.348	3.733 *
With in	21	41.333	1.968	
Total	27	85.421		

Conclusion

The data obtained regarding above mentioned parameters were statistically analyzed using MSTAT C. It was concluded from the present study that genetic variability exists among cotton varieties for growth, nutrient uptake and utilization at adequate as well as deficient K levels. It was also concluded that the cotton cultivars existed with the potential to grow better under K deficiency stress. However, field verification of the result is needed for final conclusion and recommendation.

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