

DIFFERENTIAL POTASSIUM REQUIREMENT AND ITS SUBSTITUTION BY SODIUM IN COTTON GENOTYPES

Liaqat Ali, Rahmatullah, A.M. Ranjha, Tariq Aziz, M.Aamer Maqsood and M. Ashraf
Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad

Sodium (Na) can substitute different osmoregulatory functions of potassium (K) in several crop species. Inter and intra-specific variations in crop species have been reported for (K) uptake and use efficiency. We studied 30 cotton genotypes in hydroponics for growth response, K use efficiency and potassium substitution by sodium. The treatments were, deficient K (0.3mM), adequate K (3.0mM) and deficient K (0.3mM) + Na (2.7mM). The cotton cultivars differed significantly ($p < 0.01$) in biomass production. The three treatments significantly ($p < 0.05$) differed in total dry matter, root: shoot ratio, total K uptake and K use efficiency (KUE) in various cotton genotypes. Greater efficiency in total dry matter production (6.0 g plant^{-1}) in NIBGE-2 and minimum ($2.15 \text{ g plant}^{-1}$) in PB-899 per unit of K concentration at deficient K was observed. At adequate K a substantial increase (45%) in mean total dry weight was obvious compared to deficient K. At deficient K maximum K concentration (18.2 mg g^{-1}) and total K uptake ($105 \text{ mg plant}^{-1}$) were noted in NIBGE-2. Addition of 2.7 mM sodium to deficient K level, increased mean total dry weight by 38% compared to deficient K only. In deficient K + Na treatment maximum total dry matter was produced again by NIBGE-2 and minimum by MNH-786. Root: shoot ratio didn't differ by sodium addition to deficient K. The root: shoot ratio was maximum in FH-115 and minimum in PB-843.

The results confirmed that screening of genotypes on the basis of their KUE and K substitution by Na could be an effective approach for categorizing crops under K deficient condition for their growth and yield. Overall genotype NIBGE-2 had the medium potential for making better growth on K deficient soils because of more total dry matter, KUE and K, Na uptake in shoot.

Key words: Genetic variability, substitution, KUE, cotton.

INTRODUCTION

Exploitation of genetic variability for increased potassium use efficiency (KUE) and K substitution by Na can substantially increase crop productivity in low input sustainable agricultural systems particularly in developing countries. The use of fertilizer has been mainly confined to the application of N and P, while ignoring K. This has been due to the general consensus that soils of Pakistan contain sufficient amount of K due to the dominance of illite in their clay fractions (McLean and Watson, 1985). Although total soil K is quite high but its release rate from soil matrix generally fall short to meet the K requirement of crops (Tisdale *et al.*, 2000). The increase in cropping intensity and introduction of high yielding varieties have also resulted in depletion of soil K reserves, which in turn caused negative K balance and also had erratic response. Sodium can substitute K to a large extent in its non-specific functions within the vacuole. This can result in K availability for specific functions within the cell (El-sheikh and Ulrich, 1970). If supply is limiting, retranslocation of K from other plant parts or increased uptake of cations such as Na, Mg and Ca or organic solutes (Marschner, 1995) to at least partially substitution for the possible loss of non-specific(vacuolar) functions of K. It is well recognized that varieties within species widely differ in their ability

to take up and utilize mineral elements. A possible way for increasing growth and cotton yield is the exploitation of genetic variability, that exists among different varieties of the crop for different utilization of mineral nutrients in the growth medium. Many studies have been undertaken to examine the extent of genetic variations in mineral nutrition including differential growth and yield response to varying nutrient levels, nutrient uptake and utilization (Gill, *et al.*, 1997, Pettigrew *et al.*, 1996 and Yadav and Swami, 1988). Cassman *et al.*, (1989) conducted an experiment on two cotton cultivars to study their differential response at various K levels in terms of K-use efficiency. Variation existed among sweet potato genotypes in K concentration, accumulation and K efficiency ratio in the field. Among various plant parts, petiole contained the highest K accumulation at maturity (George *et al.*, 2002 and Jennifer *et al.*, 2004). Because the majority of the K ion is located within the central vacuole of plant cells where it functions as an osmoticum, changes in measured tissue K concentrations mostly reflected changes in vacuolar K levels. However growth and essential plant requirements for K appear to relate more to its role as an activator of biochemical processes in the cytosole (Leigh and Wyn Jones, 1986). Cytosolic K is not replaceable in its functions by other cations and any decrease in cytosolic K concentrations will affect many K-specific processes in

the plant (Lauchli and Plugar 1978) reducing severely plant growth and hence yield. Under K-deficiency cell first attempts to maintain cytosolic K concentrations at the cost of vacuolar, particularly in plant parts those are most vital for further crop development. This may then lead to increased root K uptake. It mainly involves maintenance of the osmotic potential of cells. The existence and understanding of real genetic differences may provide a basis for engineering "high-K" crops to reduce their K requirements (Leigh, 1989). Use of the low fertility tolerant cultivars should be maximized in breeding and genetic studies to enhance sustainable farming systems (Singh *et al.*; 2003). Fageria and Barbosa (1982) classified rice genotypes into four categories on the basis of average yield of the P-stress plants and grain yield response index. The categories include efficient responsive, efficient nonresponsive, nonefficient responsive and nonefficient nonresponsive. The extent to which Na can replace K varies between different plant species, different cultivars of the same species and even between different leaves of the same plant. Na can replace K in red beet without adversely affecting metabolic functions such as water relations, photosynthetic rates and growth was determined by Subbarao *et al.*, (1999). Younger leaves relying more on K than older ones (Lindhauer *et al.*, 1990). Interestingly, halophytes require less K for growth than glycophytes (Marschner, 1995), indicating a link between the ability to substitute K with Na and salt tolerance. Potassium substitution and growth stimulation by Na are of great interest for improved crop production and K fertilizers management. Keeping in view the above facts, the present hydroponic study aimed at, identifying cotton cultivars efficient in K utilizations and its substitution by Na.

MATERIALS AND METHODS

A hydroponic experiment was conducted to study the growth response of 30 cotton cultivars in a wire-house. Seeds of 30 cotton genotypes were germinated in pre-washed river bed sand taken in polythene lined iron trays. Sand in the trays was moistened with distilled water for germination. One week old uniform cotton seedlings were transplanted in foam plugged holes of thermopal sheet, floating on 200 L of one half strength of Johnson's modified solution (Johnson *et al.*, 1957) in three polythene lined iron tubs. Continuous aeration was provided with the help of aeration pump. The treatments included; 0.3mM K, 3.0mM K, and 0.3mM K + 2.7mM Na, used as KNO₃ and Na₂SO₄. The pH of the solution was maintained daily at 5.5 ± 0.5. The experiment was laid out according to completely randomized factorial design with six replicates of each

cultivar (Steel and Torrie 1980). Average temperature in the greenhouse was 33±5 °C at different times of day and 23±5°C during the night for the experimental period. Relative humidity dropped to 31 % at mid day and increased to 80 % at mid night. Plants harvested five weeks after transplanting were separated into shoot and root before drying them to a constant weight at 70°C in a forced air oven for their dry matter yield. Sodium and K in both shoots and roots were determined after wet digestion with diacid mixture (HNO₃, HClO₄). Potassium stress factor %, KUE and % substitution were also calculated by following formula

$$KSF = \frac{SDW_{adequate\ K} - SDW_{deficient\ K}}{SDW_{adequate\ K}} \times 100$$

$$KUE = \frac{1}{K\ Conc} \times SDM$$

$$\% \text{ Substitution} = 100 * (KSF_{def\ K} - KSF_{def\ K + Na}) / KSF_{def\ K}$$

The data collected was analyzed statistically using software MSTAT-C (Steel and Torrie, 1980).

RESULTS

Various cotton genotypes differed significantly ($p < 0.01$) in total dry matter and root: shoot ratio at deficient and adequate K supply in root medium (Table 1). Total dry matter production by cotton genotypes increased two folds when K supply was increased from 0.3 mM to 3.0 mM in growth medium. It ranged between 2.15 and 6.0 g plant⁻¹ with deficient K in the rooting medium. Under K deficiency, maximum total dry mass was produced by NIBGE-2 and minimum by PB-889. A substantial increase (45%) in mean total dry weight was obvious at adequate K compared to deficient K. At deficient K supply maximum root shoot ratio was observed in MNH-700 and minimum in RH-510.

Thirty cotton genotypes were classified into four classes (Fig-1). Addition of 2.7 mM sodium to deficient K level, increased mean total dry weight by 38% compared to deficient K only. In deficient K+Na treatment maximum total dry matter was produced again by NIBGE-2 and minimum by MNH-786. Root:shoot ratio didn't differ by sodium addition to deficient K. The root shoot ratio was maximum in FH-115 and minimum in PB-843.

Addition of 2.7 mM sodium to deficient K level, increased mean total dry weight by 38% compared to deficient K only. In deficient K + Na treatment maximum total dry matter was produced again by NIBGE-2 and minimum by MNH-786. Root: shoot ratio didn't differ by sodium addition to deficient K. The root shoot ratio was maximum in FH-115 and minimum in PB-843.

Table 1. Ranges and mean values of total dry matter (g plant^{-1}) and root shoot ratio of four classes of 30 cotton genotypes grown at deficient K, deficient K + Na, and adequate K

Name of genotypes	Classes	Total Dry Matter						Root Shoot Ratio					
		Deficient K			Deficient K + Na			Adequate K			Deficient K		
		Range	Mean	Range	Mean	% increase	Range	Mean	% increase	Range	Mean	Range	Mean
NIBGE-2, NIAB-98, BH-163, CRIS-460, SLH-317, FH-2925, NIAB-2, ALSEEMI-1, FH-2006, NIAB-884, H-151-F2	Efficient Responsive	3.2-6.0	4.3	3.7-8.2	5.4	7-51	4.3-10	6.9	31-118	0.04-0.13	0.078	0.05-0.13	0.081
SLH-279, MNH-732, PB-843, SLH-284	Efficient Non Responsive	3.1-3.8	3.4	4.1-6.5	5.3	22-58	6-7.7	6.7	71-109	0.05-0.09	0.067	0.03-0.08	0.06
RH-510, NIAB-111, NIAB-999	Non Efficient Responsive	2.7-2.9	2.8	3.4-5.3	4.3	27-80	5.6-6.8	6.2	92-150	0.04-0.09	0.06	0.05-0.07	0.06
CIM-473, NEELUM-NS-11, NIAB-824, TH-41/83, CIM-499, FH-2000, FH-115, FH-1000, PB-899, MNH-786, MNH-700, RH-512.	Non Efficient Non Responsive	2.1-2.8	2.4	2.2-5.6	3.5	0.3-151	3.3-8.9	4.8	19-215	0.04-0.28	0.095	0.04-0.15	0.1

Table 3. Ranges and mean values of Na concentration (mg g^{-1}), total Na uptake (mg plant^{-1}) and K:Na ratio in shoot of the four classes of 30 cotton genotypes grown at Deficient K+Na.

Name of genotypes	Classes	Na concentration in shoot		Total Na uptake		K : Na	
		Range	Mean	Range	Mean	Range	Mean
NIBGE-2, NIAB-98, BH-163, CRIS-460, SLH-317, FH-2925, NIAB-2, ALSEEMI-1, FH-2006, NIAB-884, H-151-F2	Efficient Responsive	6.1-18.6	9	49-139	75.5	0.6-1.74	1.1
SLH-279, MNH-732, PB-843, SLH-284	Efficient Non Responsive	7.5-13.6	11.2	48-101	75	0.7-1.0	0.95
RH-510, NIAB-111, NIAB-999	Non Efficient Responsive	4.5-8.5	7	35-53	48	1.0-1.8	1.3
CIM-473, NEELUM-NS-11, NIAB-824, TH-41/83, CIM-499, FH-2000, FH-115, FH-1000, PB-899, MNH-786, MNH-700, RH-512.	Non Efficient Non Responsive	6.5-22.1	8.9	38-88	51.8	0.5-5.4	1.6

Table 2(a). Ranges and mean values of K concentration (mg g^{-1}) total K uptake (mg plant^{-1}) and potassium use efficiency ($\text{g}^2 \text{mgK}^{-1}$) in shoot of the four classes of 30 cotton genotypes grown at deficient K, deficient K + Na, and adequate K

Name of genotypes	Classes	K concentration						Total K uptake					
		Deficient K		Deficient K + Na		Adequate K		Deficient K		Deficient K + Na		Adequate K	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
NIBGE-2, NIAB-98, BH-163, CRIS-460, SLH-317, FH-2925, NIAB-2, ALSEEMI-1, FH-2006, NIAB-884, H-151-F2	Efficient Responsive	10.5-18.2	13.6	8.9-12.7	10.4	31.4-61.2	42.3	38-105	55.6	35-100	50.1	134-485	170
SLH-279, MNH-732, PB-843, SLH-284	Efficient non Responsive	12.9-15.5	14.4	7.3-14.0	9.4	35.9-41.8	38.2	40-59	49.3	36-89	56	209-277	250
RH-510, NIAB-111, NIAB-999	Non Efficient Responsive	9.1-10.6	10	8.2-9.8	9	31.0-35.4	33.1	24-30	27.3	28-50	37	181-236	215
CIM-473, NEELUM-NS-11, NIAB-824, TH-41/83, CIM-499, FH-2000, FH-115, FH-1000, PB-899, MNH-786, MNH-700, RH-512,	Non Efficient Non Responsive	11.5-14.7	13.4	8.6-13.7	11.6	25-44	32.6	28-39	28.6	23-71	26	96-380	140

Table 2(b). Ranges and mean values of K concentration (mg g^{-1}) total K uptake (mg plant^{-1}) and potassium use efficiency ($\text{g}^2 \text{mgK}^{-1}$) in shoot of the four classes of 30 cotton genotypes grown at deficient K, deficient K + Na, and adequate K

Name of genotypes	Classes	K Use Efficiency					
		Deficient K		Deficient K+Na		Adequate K	
		Range	Mean	Range	Mean	Range	Mean
NIBGE-2, NIAB-98, BH-163, CRIS-460, SLH-317, FH-2925, NIAB-2, ALSEEMI-1, FH-2006, NIAB-884, H-151-F2	Efficient Responsive	0.25-0.44	0.31	0.28-0.61	0.44	0.11-0.22	0.16
SLH-279, MNH-732, PB-843, SLH-284	Efficient non Responsive	0.22-0.23	0.23	0.34-0.70	0.5	0.14-0.18	0.15
RH-510, NIAB-111, NIAB-999	Non Efficient Responsive	0.25-0.28	0.26	0.41-0.53	0.46	0.16-0.20	0.18
CIM-473, NEELUM-NS-11, NIAB-824, TH-41/83, CIM-499, FH-2000, FH-115, FH-1000, PB-899, MNH-786, MNH-700, RH-512,	Non Efficient Non Responsive	0.14-0.21	0.16	0.19-0.42	0.28	0.08-0.19	0.12

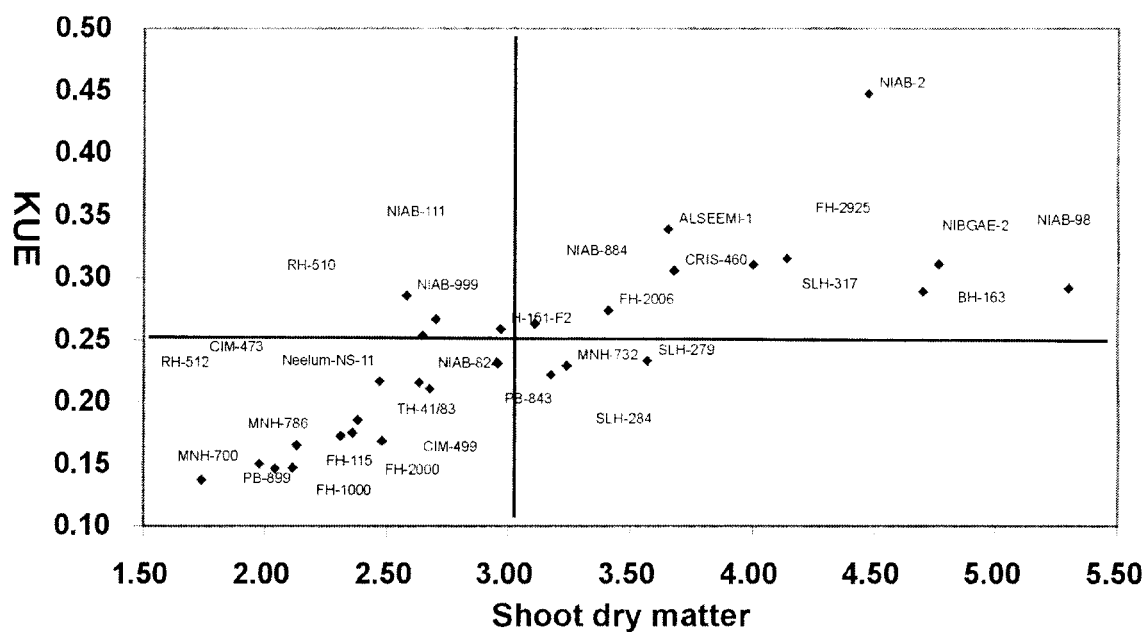


Fig.1 KUE and Categorization of cotton cultivars

Potassium concentration in shoot was significantly affected by K supply, genotypes and their interaction (Table 2a). Genotypes grown with 3 mM K had about three fold more K in their shoot compared to those grown with 0.3 mM K. Maximum K concentration in shoot was observed in NIBGE-2 at deficient K and minimum in NIAB-999. It ranged between 9.1 to 18.2 mg g⁻¹. At adequate K, maximum K concentration was in NIBGE-2 and minimum in FH-1000. Total K uptake by cotton cultivars was increased five fold when K supply increased from 0.3 mM K to 3.0 mM K in growth medium. Under deficient K total K uptake was maximum in NIBGE-2 and minimum by NIAB-999.

Mean decrease in shoot K concentration in genotypes supplied with Na was 19% compared to those grown with 0.3 mM K alone. The maximum shoot K concentration was in SLH-279 and minimum in PB-843 at deficient K +Na. Mean total K uptake did not change significantly by adding Na in deficient K. Under deficient K +Na, maximum total K uptake was noted again by NIBGE-2 and minimum by MNH-786. Mean maximum KUE (40% and 62.5%) was observed higher in genotypes grown with deficient K +Na than those of grown with deficient K and adequate K respectively (Table 2b). The differences in Na concentration and total Na uptake in shoot of cotton genotypes grown with deficient K +Na were significant (Table-3). The Na concentration in shoot ranged between 2.29 to 22.11

mg g⁻¹ but differences in total Na uptake in shoot were 4.0 fold among the genotypes.

DISCUSSION

Total dry matter of different genotypes was increased and ranged from 2.15 to 6.0 and 3.34 to 10.01 g plant⁻¹ at deficient K, and adequate K respectively. Significant differences among genotypes in dry matter were due to intra-specific variations for K-use efficiency. Some varieties used K more efficiently than others. As NIBGE-2 exhibited highest total dry matter at deficient K, because it used K more efficiently (Cassman *et al.*, 1989 in cotton, Gill *et al.*, 1997 in wheat and Pettigrew *et al.*, 1996 in cotton cultivars). At adequate K, mean increase in root: shoot ratio of cotton genotypes was due to high accumulation of K in the root. At deficient K supply to root medium significant increase in K concentration and total K uptake was because of the differences in ability of some genotypes to accumulate and take up K more efficiently than others (Yadav and Swami; 1988, George *et al.*; 2002, Jennifer *et al.*, 2004 and Singh *et al.*, 1991). Mean increase (50%) in KUE among different genotypes at deficient K supply was evident in increased dry matter per unit of K concentration used. Eleven genotypes can be claimed as efficient and responsive to potassium since their shoot dry matter increased as the potassium supply in the growth medium was increased (Fig 1). Twelve genotypes are grouped as non efficient non

responsive, as they produced minimum dry mass at both level of potassium.

Total dry matter distributed within range i.e. 2.24-8.24 g plant⁻¹ at deficient K +Na. By adding Na in deficient K increased yield due to K substitution by Na in its certain non-specific functions. Overall, the genotypes performed best in total dry matter; those were highest in percent substitution and lowest in KSF (%). More K substitution withstands the K deficiency resulting in increased growth (Subbarao *et al.*, 1999). By addition of sodium with deficient K increased KUE (>500 mg² mg⁻¹ K) as showed in NIBGE-2 followed by PB-843 and NIAB-111. K:Na ratio (>1) promoted less total Na uptake (Table 3) in NIAB-111, FH-1000 and MNH-786, But NIBGE-2 depicted high total Na uptake, so more K substitution occurred.

CONCLUSION

The results confirmed that screening of genotypes on the basis of their KUE and potassium substitution by sodium could be an effective approach for enhancing the growth and yield of crops under K deficient conditions. Overall genotype NIBGE-2 had the highest potential for better growth in K deficient soils due to increased TDM and high total K uptake in shoot.

LITERATURE CITED

- Cassman, K.G., T.A. Kerby, B.A. Roberts, D.C. Bryant and S.M. Brouder. 1989. Differential response of two cotton cultivars to fertilizer and soil potassium. *Agron. J.* 105: 294-296.
- El-Sheikh, A.M. and Ulrich. 1970. Interaction of Rubidium, Sodium and Potassium on the nutrition of sugar beet plants. *Plant Physiol.* 46, 645-649
- Fageria, N.K. and M.P. Barbosa. 1982. Screening rice cultivars for low level of phosphorus tolerance. *R. Brai. Ci. Solo* 6: 146-151.
- George, M.S., G. Lu and W. Zhou. 2002. Genotypic variation for K uptake and Utilization efficiency in sweet potato. *Field Crop Res.* 77: 7-15.
- Gill, M.A., M.I. Ahmad and M. Yaseen. 1997. Potassium deficiency stress tolerance and potassium utilization efficiency in wheat genotypes. T. Ando *et al.* (Eds.) *Plant nutrition for sustainable food production and environment*: 321-322.
- Jennifer, L., Fridgen and Jac J. Varco. 2004. Dependency of Cotton Leaf Nitrogen, Chlorophyll, and Reflectance on Nitrogen and K availability. *Agron. J.* 96:63-69.
- Johnson, C.M., R.R. Stout, T.C. Broyer and A.B. Carlton. 1957. Comparative Chlorine requirements of different species. *Plant Soil.* 8:327-353.
- Lauchli, A., and R.P. Pluger. 1978. Potassium transport through plant cell membrane and metabolic role of potassium in plants. P, 111-163 in potassium research-review and trends. International Potash Institute, Bern.
- Leigh, A. 1989. Potassium concentration in whole plants and cells in relation to growth. p,117-126. In methods of K-research in plants International Potash Institute, Bern.
- Leigh, R.A. and R.G. Wyn. Jones. 1986. In: *Advances in plant nutrition*, Vol. 2 Ed. P.B. Tinker and A. Lauchli, p. 249-279, Praegar, New York.
- Marschner, H. 1995. *Mineral nutrition of higher plants*, 2nd ed. Academic press, San Diego.
- McLean, E.O. and M.E. Watson. 1985. Soil measurements of plant-available K. In: Munson, R.D. (Ed.), *Potassium in Agriculture*. Soil Sci. Soc. Am., Madison, WI, pp.227-308.
- Pettigrew, W.T., J.J. Heitholt and W.R. Meredith Jr. 1996. Genotypic interaction with potassium and N in cotton of varied maturity. *Agron. J.* 88(1): 89-93.
- Singh, D., M.S. Brar and A.S. Brar. 1991. Response to Potassium application and its Critical levels for American cotton. *J. Indian Soc. Soil Sci.*, 39: 494-499.
- Singh, S.P., H. Teron, C.G. Munoz, J.M. Osorno, J.C. Takegami and M.D.T. Thung. 2003. Low soil fertility tolerance in land races and improved common bean genotypes. *Crop Sci.* 43: 110-119.
- Steel, R.G.D. and J.H. Torrie. 1980. *Principles and Procedures of Statistics*. McGraw Hill Book Co., Inc. New York.
- Subbarao, G.V., R.M. Wheeler, G.W. Stutte and L.H. Levine. 1999. How far can sodium substitute for potassium in red beet? *J. Plant Nutr.*, 22: 1745-1761
- Tisdale, S., W.L. Nelson and J.D. Beaton. 2000. *Soil Fertility and Fertilizer*. 7th edition McMillan Co. New York, USA.
- Yadav, B.S. and B.N. Swami. 1988. Effect of potassium fertilization on dry matter yield and composition and uptake of nutrient by maize and change in soil potassium on cropping. *J. Indian Soc. Soil Sci.*, 36:739-742.