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EVALUATING POTASSIUM-USE-EFFICIENCY OF FIVE COTTON GENOTYPES OF PAKISTAN

ZIA-UL-HASSAN[1*], K.A. KUBAR[1], I. RAJPAR[1], A.N. SHAH[2], S.D. TUNIO[2], J.A. SHAH[3] AND A.A. MAITLO[4]

[1]*Department of Soil Science, Sindh Agriculture University, Tandojam, Sindh, Pakistan*
[2]*Department of Agronomy, Sindh Agriculture University, Tandojam, Sindh, Pakistan*
[3]*Nuclear Institute of Agriculture Tandojam, Sindh, Pakistan.*
[4]*Agriculture Research Institute, Tandojam, Sindh, Pakistan*
**Corresponding author's e-mail: zhnshah@gmail.com*

Abstract

Potassium (K) deficiency in Pakistani soils has been recently reported as the major limiting factor affecting sustainable cotton production. The present study was conducted to envisage how K nutrition affect the growth, biomass production, yield and K-use-efficiency of five cotton genotypes, NIBGE-3701, NIBGE-1524 (Bt-transgenic), Sadori, Sindh-1 and SAU-2 (non-Bt conventional), commonly grown in Pakistan. All five genotypes were raised at deficient and adequate K levels, i.e. 0 and 60 kg K_2O ha^{-1}, respectively. The experiment was performed in plastic pots following a completely randomized factorial design with three repeats. Adequate K nutrition significantly increased various plant growth traits and yield of all cotton genotypes under study, viz. number of sympodia (21%), number of leaves (34%), leaf dry biomass (30%), shoot dry biomass (31%), number of bolls (50%) and yield of seed cotton (92%). Substantial variations were observed among cotton genotypes for their K-use-efficiency and K-response-efficiency. Sadori and SAU-2 were screened as most K-use-efficient cotton genotypes, while Sindh-1 and SAU-2 were ranked as the most K-responsive cotton genotypes. Interestingly, Sadori did not respond to K nutrition. Moreover, Bt cotton genotypes accumulated more K as compared to non-Bt genotypes. The cotton genotype SAU-2 was identified as 'efficient-response' genotype for better adaptation for both low- and high-K-input sustainable cotton agriculture systems.

Introduction

Cotton (*Gossypium hirsutum* L.) is considered as the most important cash crop of Pakistan. However, according to the recent data available, yield of cotton in Pakistan remains highly stagnant during last decade, i.e. 714 to 731 kg ha^{-1} during 2005-06 to 2010-11, respectively (Anon., 2012).

Plant nutritionists in Pakistan have recently established this yield stagnancy in cotton with the rapidly decreasing K status of the soils of Pakistan (Zia-ul-hassan *et al*., 2011). It is interesting to note that a big myth exists about the adequate K status of Pakistani soils, even among the plant nutritionists, despite the prevalence of K-deficiency in Pakistani soils, especially in major benchmark soils series (Zia-ul-hassan *et al*., 2008).

A number of crop species are found responding well to adequate K nutrition e.g. maize (Nawaz *et al*., 2006; Yousra *et al*., 2013) and cotton (Ali & Ali, 2011; Zia-ul-hassan & Arshad, 2010; Zia-ul-hassan & Arshad, 2011).

Potassium greatly contributes for yield and quality of cotton as an essential macronutrient (Wang & Chen, 2012). Interestingly, cotton requires K in amounts equal to that of nitrogen (Zia-ul-hassan & Arshad, 2010), due to its involvement in various important physiological and biochemical process (Zhao *et al*., 2001; Wang *et al*., 2012) and consequent beneficial effects on its growth and development, yield and the quality of fiber (Pettigrew *et al*., 1996; Akhtar *et al*., 2003).

Adequate K nutrition enhances the efficiency of photosynthetic apparatus (Zhao *et al*., 2001; Wang *et al*., 2012) and promotes plant roots (Zia-ul-hassan & Arshad, 2010). Similar to the genotypes of other crop species, cotton genotypes also differ in their K requirement and this genotypic variation is of great importance for future breeding programs focusing on low-K-input agriculture (Akhtar *et al*., 2009; Yang *et al*., 2011; Wang & Chen, 2012). K-efficient cotton genotypes accumulate higher K during fruit development (Cassman *et al*., 1989) due to their active root system (Brouder & Cassman, 1994).

Because of their high biomass production, Bt cotton genotypes require more K and are considered more K-deficiency prone than non-Bt genotypes (Zhang *et al*., 2007). In Pakistan, the cultivation of Bt cotton genotypes is increasingly become popular due to higher yield. However, farming community in Pakistan mostly avoids involving K in their cotton production programs, due mainly to cost of fertilizer K.

With these considerations in mind, this study was planned to evaluate the K-use-efficiency of five cotton genotypes of Pakistan in order to identify the most potential candidate genotype(s) for low-K-input sustainable cotton production in Pakistan.

Materials and Methods

This pot study was followed a completely randomized factorial arrangement involving five cotton genotypes, viz. NIBGE-3701, NIBGE-1524(Bt), Sadori, Sindh-I and SAU-II (conventional), grown in plastic pots at two K levels i.e. 0 and 60 kg ha^{-1}. The crop also received recommended amount of nitrogen (N) and phosphorus (P) (150-75 kg N-P_2O_5 ha^{-1}). Full P and K, along with half of N, was applied to the soil at the time of soil preparation. The leftover N was given to crop at boll opening.

The clay soil under study was alkaline in nature (pH: 8.1), non-saline (EC: 0.40 dS m^{-1}) and low in organic matter content (0.64%) and AB-DTPA-K (105 mg kg^{-1}). Cotton seeds were delinted (1.0 ml sulphuric acid per 10.0 g of cotton seed) and surface sterilized (5% sodium hypochlorite solution for 5 min.) to avoid fungus infection.

A total of 10 delinted seeds were sown in all pots which were later thinned to two uniform size seedlings. The crop was raised under the recommended production technology with respect to various agronomic practices, irrigation requirement, and weed and insect pest control, throughout the life span of the crop. The pots were regularly rotated on twice a week basis to provide homogenous environment to all the experimental units.

The crop was harvested at maturity. The data for various plant traits were recorded, viz. height of plant, monopodial and sympodial branches, leaf number, leaf and shoot fresh and dry weights, total bolls and seed cotton yield.

Potassium relations of cotton plants were evaluated as suggested earlier (Zia-ul-hassan *et al*., 2011). The K uptake was calculated as a product of dry weight of shoot and its K concentration Zhang *et al*., (2007). K use efficiency was calculated as shoot dry weight over shoot K concentration (Siddiqi & Glass, 1981).

The analysis of variance and correlation analysis were performed using "Statistix ver.8.1". Tukey's honestly significant difference test at alpha 0.05 was employed to separate the treatment means.

Results

Adequate K nutrition significantly ($p<0.05$) affected all the plant traits of cotton genotypes under study, except plant height and number of monopodia (Table 1). The cotton genotypes were also significantly ($p<0.05$) different for their various plant characteristics at two K levels. Consequently, the interactive effect of these two sources of variance was also highly significant and different plant traits of cotton genotypes differently affected by this interaction.

Number of sympodia per plant: Adequate K nutrition enhanced the sympodial branches of cotton plants up to 21% as against no K application (Fig. 1). However, genotypes behaved differently in producing sympodial branches at two different levels of K. Under K deficiency stress, maximum (16.7) sympodia were noted for SAU-2 while minimum sympodia were observed in case of NIBGE-1524 (13.2). When K was adequately supplied to cotton plants, maximum sympodia were counted on NIBGE-1524 (19.9) while minimum sympodia were found on Sindh-1 (16.1).

Number of leaves per plant: Cotton plants produced 34% more leaves when supplied with adequate dose of K as compared to the treatment with no K (Fig. 1). Nonetheless, considerable variation existed among cotton genotypes and they produced varying number of leaves. Under K deficient condition, SAU-2 produced maximum leaves (11.6) while minimum leaves were counted on NIBGE-1524 (8.3). However, under K deficiency stress, NIBGE-1524 produced maximum leaves (14.5) while minimum leaves were observed on SAU-2 (13.3).

Leaf fresh weight (g plant^{-1}): Potassium nutrition increased leaf fresh biomass up to 20% as against no K level (Fig. 1). However, genotypes were not alike in their behavior to various levels of K. When no K was applied to cotton genotypes, SAU-2 recorded maximum leaf fresh weight per plant (7.2) while minimum was noted in case of NIBGE-1524 (6.1). Similarly, under adequate K nutrition, NIBGE-1524 offered maximum leaf fresh biomass (9.1) while Sindh-1 (6.9) offered minimum leaf fresh biomass.

Leaf dry weight (g plant^{-1}): When K was supplied to cotton plants in adequate amounts, their leaf dry weight increased up to 30% (Fig. 1). However, this effect of K nutrition was highly genotype specific at two K levels. At deficient K level, SAU-2 produced maximum leaf dry weight per plant (1.5) while NIBGE-1524 produced minimum (1.1). Under K adequate condition, NIBGE-1524 responded more than any other genotype and produced maximum leaf dry weight per plant (1.9) while Sindh-1 produced minimum (1.5) leaf dry weight.

Shoot fresh weight (g plant^{-1}): Potassium nutrition increased shoot fresh biomass up to 16% as against deficient level of K (Fig. 2). However, at two different levels of K the behavior of cotton genotypes was different. Under K deficient condition, SAU-2 recorded highest shoot fresh weight per plant (10.4) while NIBGE-1524 offered minimum (9.6) shoot fresh weight. In contrast, NIBGE-1524 produced maximum shoot fresh weight (9.6) under adequate K nutrition but NIBGE-1524 produced maximum shoot fresh biomass (12.1) while Sindh-1 and Sadori produced minimum shoot fresh weight (~11.15).

Table 1. Significance of mean squares from analysis of variance of various parameters of cotton genotypes at deficient and adequate levels of potassium

Parameter	K-Levels (K)	Genotype (G)	K × G
Plant height	NS	NS	NS
Number of monopodia	NS	NS	NS
Number of sympodia	74.26***	3.84**	9.44***
Number of leaves	86.70***	2.97**	5.72***
Leaf fresh weight	11.38***	0.71***	2.18***
Leaf dry weight	1.18***	0.06***	0.08***
Shoot fresh weight	18.88***	0.30***	0.55***
Shoot dry weight	14.00***	0.65***	1.13***
Number of bolls	56.58***	0.36*	1.72***
Seed cotton yield	469.65***	7.83***	18.78***
K uptake	6029.34***	119.05***	335.12***
K use efficiency	NS	7.98***	1.44**

Note: *, ** and *** represent significance levels at alpha 0.05, 0.01, and 0.001 obtained through honestly significant difference (HSD) test. 'NS' represents non-significance

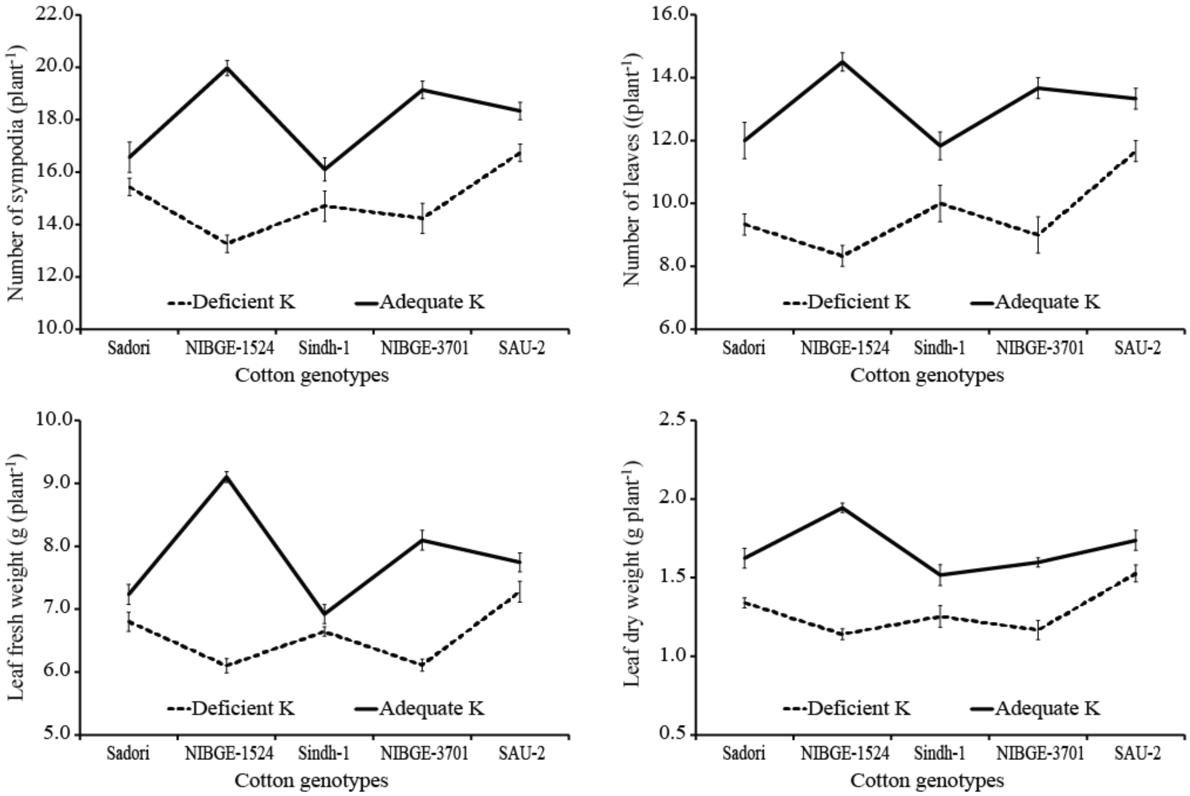

Fig. 1. Number of sympodia, number of leaves, leaf fresh weight and leaf dry weight of Bt and non-Bt cotton genotypes under deficient and adequate K levels.

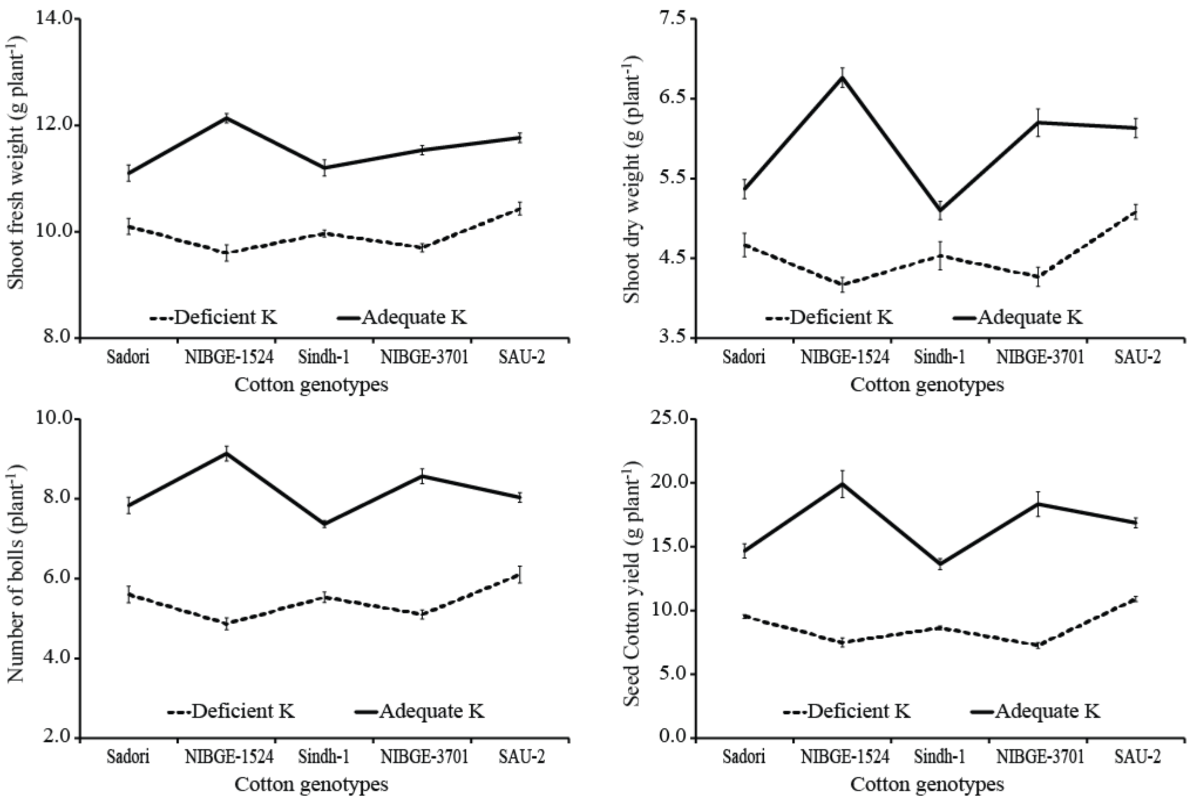

Fig. 2. Shoot fresh weight, shoot dry weight, number of bolls and seed cotton yield of Bt and non-Bt cotton genotypes under deficient and adequate K levels.

Shoot dry weight (g plant^{-1}): When cotton genotypes received adequate K nutrition their shoot dry weight increased to 31% as compared to the situation when they did not receive any K (Fig. 2). Nonetheless, cotton genotypes performed differently at two levels of K. When no K was applied, SAU-2 gave highest shoot dry weight per plant (5.1) while NIBGE-1524 recorded minimum (4.2) shoot dry weight. Contrarily, NIBGE-1524 produced maximum shoot fresh weight (9.6) under optimum K nutrition but NIBGE-1524 offered maximum shoot dry biomass (6.8) while Sadori produced minimum shoot fresh weight (5.3).

Number of bolls per plant: Adequate K application to cotton plants enhanced their number of bolls up to 50% as compared to the condition when they did not receive any K (Fig. 2). Moreover, the response of cotton genotypes at different K levels was different. SAU-2 recorded maximum number of bolls (6.1) under optimum K while NIBGE-1524 offered minimum (4.8) number of bolls. However, NIBGE-1524 produced maximum number of bolls (9.1) under adequate K nutrition while Sindh-1 produced minimum number of bolls (7.3).

Seed cotton yield (g plant^{-1}): Adequate K nutrition enhanced seed cotton yield up to 92% as against its deficient condition (Fig. 2). Moreover, cotton genotypes behaved differently two varying K levels. Under deficient K nutrition, SAU-2 gave maximum seed cotton yield (10.9) while NIBGE-3701 offered minimum (7.2) seed cotton yield. However, NIBGE-1524 produced maximum yield of seed cotton (19.9) under optimum K nutrition while Sindh-1 produced minimum seed cotton yield (13.6).

K uptake (g plant^{-1}): When cotton plants received adequate K nutrition, their K uptake increased up to 3.6-fold as compared to their K uptake at deficient K level (Fig. 3). However, genotypic variation existed among cotton genotypes for their K uptake at two K levels. SAU-2 accumulated maximum K (15) under K deficiency stress while NIBGE-3701 accumulated minimum K (7.7). At adequate K level, maximum K uptake was noted for NIBGE-1524 (55.3) as against minimum K uptake observed in case of SAU-2 (29.2).

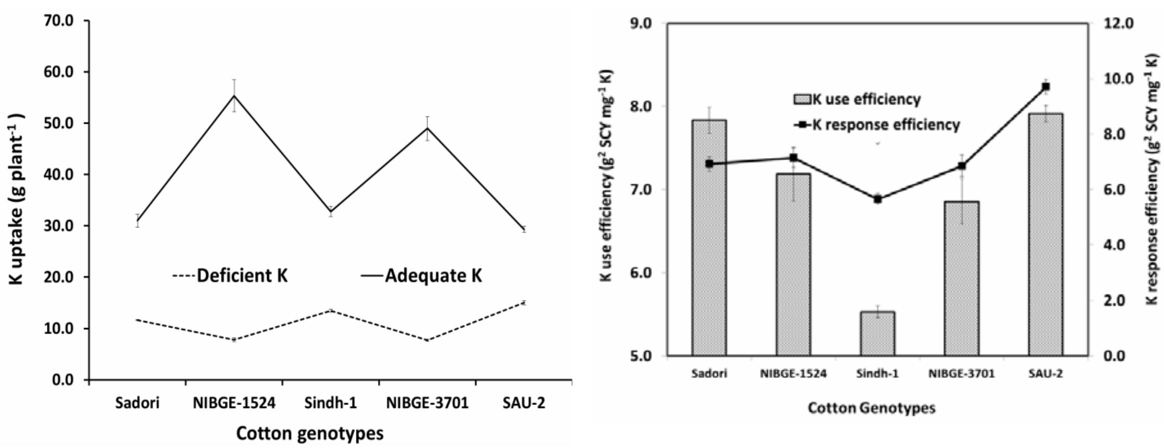

Fig. 3. K uptake and K use efficiency of Bt and non-Bt cotton genotypes under deficient and adequate K levels.

K efficiency (g^2 SCY mg^{-1} K): Cotton genotypes were identified for their K-use-efficiency (under K deficiency stress) and K-response-efficiency (at adequate K level). For this purpose, the genotypes were considered as treatment and the ANOVA was performed based up on one-way completely randomized design. As expected, genotypes were highly significantly different for their K-use-efficiency and K-response-efficiency (Fig. 3). Sadori and SAU-2 were identified as most K-use-efficient cotton genotypes. Sindh-1 and SAU-2 were categorized as the most K-responsive cotton genotypes. The genotype Sadori did not respond to K nutrition. Moreover, Bt cotton genotypes accumulated maximum K as compared to non-Bt genotypes.

Relationship of seed cotton yield various plant traits: The correlation analysis (Table 2) revealed that under K deficient condition enhanced K uptake and improved plant growth traits increased the seed cotton yield of K-use-efficient cotton genotypes. While under adequate K level, increased dry weight of shoot, leaf fresh biomass, sympodia and bolls governed the yield of seed cotton.

Discussion

Potassium has been considered an essential nutrient for quality cotton production, due to its vital roles in enhancing the cotton growth and development, yield and quality of fiber (Pettigrew *et al*., 1996; Akhtar *et al*., 2003; Wang *et al*., 2012). However, very little research has been done to explore the variation among different cotton genotypes of Pakistan for their K-requirement and efficiency to use K.

Cotton is highly sensitive to K deficiency and hence it becomes very difficult to claim economic yield of cotton once K deficiency symptoms appear on cotton leaves (Rosolem & Mikkelsen, 1991; Zhao *et al*., 2001). This pot study recorded significant improvements in growth and yield of cotton genotypes (Figs. 1 to 3) in response to adequate K nutrition, viz. sympodia (21%), number of leaves (34%), leaf biomass (fresh 20%, dry 30%), shoot biomass (fresh 16%, dry 31%), number of bolls (50%) and seed cotton yield (92%). Moreover, plant height and monopodia did not respond to K nutrition. These results are strongly in-line the findings of early studies reporting the beneficial effects of K nutrition in cotton production (Pettigrew & Meredith, 1997; Zia-ul-hassan *et al*., 2011; Wang & Chen, 2012).

Earlier, Makhdum *et al*., (2007) elucidated that adequate K nutrition resulted in enhanced resource translocation to the reproductive organs. Zia-ul-hassan & Arshad (2010) observed that K nutrition positively affected leaf and root growth traits of cotton genotypes enabling them to produce more biomass under K deficiency stress. Potassium nutrition promotes fruit retention in cotton by increasing the number, length and weight of sympodia (Brar *et al*., 2008). Pettigrew & Meredith (1997) observed that K-efficient cotton genotypes had less plant height and leaf number while more squares and bolls and higher dry matter and K contents as against K-inefficient cotton genotypes.

In this study, most of the plant growth traits of cotton genotypes responded well to 60 kg K ha^{-1} (Figs. 1 to 3). However, cotton genotypes with Bt and non-Bt traits differed significantly with respect to K nutrition. Gadhiya *et al*., (2009) reported improvement in most of the plant growth traits of cotton in response to 50 kg K ha^{-1}. Ali & Ali (2011) and Rasool *et al*., (2010) also found similar response of various plant traits of cotton in response to 57 and 62.5 kg K ha^{-1}.

This study also recorded significant variations among cotton genotypes for their different plant traits at two K levels. K-inefficient Bt cotton genotypes responded more strongly to K nutrition as against their K-efficient counterparts (Fig. 1 to 3). Recent literature on K use in cotton also advocates that high yielding, modern cotton genotypes require more K than their K-efficient counter parts (Zhang *et al*., 2007; Brar *et al*., 2008; Hosmath *et al*., 2011). Yang *et al*., (2011) also noted that four out of eight cotton cultivars under study affected badly under K deficiency stress were all transgenic, insect-resistant Bt cotton genotypes.

The correlation analysis revealed (Table 2) revealed that the enhanced plant growth traits under K deficiency stress determined the seed cotton yield. Same was true for the relationship of various plant traits and seed cotton yield under K deficiency stress. This was in-line to earlier report of Cassman *et al*., (1989) who noted higher K uptake by cotton during fruit development under low soil K condition. Zia-ul-hassan & Arshad (2008) concluded that the increased biomass production by efficient cotton genotypes under deficient K condition was because of their efficient leaf and root growth traits. Later work of Zia-ul-hassan *et al*., (2011) unveiled significant relationship between higher K uptake and enhanced biomass production of cotton genotypes under deficient K level. Jiang *et al*., (2011) argued that K-efficient cotton genotypes rapidly translocate dry matter into their reproductive organs and hence produce more biomass under K deficiency stress.

The study concluded that K-inefficient Bt cotton genotypes are more prone to K deficiency stress than their conventional K-efficient counterparts due to their comparatively lower K uptake under K deficiency stress. The genotype SAU-2 was ranked as 'efficient-response' genotype, well-suited for both low- and high-K-input cotton production systems.

Table 2. Relationship of seed cotton yield with some growth and yield determining parameters and with K uptake and K efficiency under deficient and adequate K conditions

Parameter	Deficient K	Adequate K
Shoot fresh weight	0.98**	0.87NS
Shoot dry weight	0.98**	0.98**
Leaf fresh weight	0.99***	0.97**
Leaf dry weight	0.98**	0.79NS
Number of sympodia	0.95*	0.99***
Number of bolls	0.96**	0.98**
K uptake	0.89*	0.84NS
K use/response efficiency	0.48NS	0.33NS

Note: *, ** and *** represent significance levels at alpha 0.05, 0.01, and 0.001 obtained through honestly significant difference (HSD) test. 'NS' represents non-significance

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