# Research Findings

**Photo 1.** Fully opened cotton bolls. Photo by authors.

## Impact of Potassium Fertilization Dose, Regime, and Application Methods on Cotton Development and Seed-Cotton Yield under an Arid Environment

**Dil Baugh Muhammad**(1), **Muhammad Naveed Afzal**(1), **Muhammad Tariq**(1)*, **and Abdul Wakeel**(2)(3)*

### Abstract

Modern cotton cultivars require more potassium (K) and its deficiency during peak bloom and boll setting period adversely affects the seed-cotton yield. The objectives of the present study were to determine the adequate K dose for the modern, transgenic cotton cultivar (*Bt*.CIM-616) grown on an arid light soil, to evaluate the effects of a split K application, and to quantify the contribution of additional foliar K applications on seed-cotton yield and its components. Two-year (2014-15) field experiments were conducted at the Central Cotton Research Institute, Multan, Pakistan, in two sets. In set-I, three K doses (0, 100 and 200 kg $K_2O$ $ha^{-1}$) were applied at sowing or were split into two or four equal applications of 50 kg $K_2O$ $ha^{-1}$ (pre-planting and 45 days after sowing or pre-planting, 30, 45 and 60 days after sowing)

(1)Agronomy Section, Central Cotton Research Institute, Multan, Pakistan
(2)Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan
(3)IPI Consultant for Pakistan, International Potash Institute (IPI), Zug, Switzerland
*Corresponding authors: mtariq131@gmail.com; abdulwakeel77@gmail.com

respectively. In set-II, the impact of pre-planting applications of 0, 100 and 200 kg $K_2O$ ha$^{-1}$, followed by four foliar sprays of 2% $K_2SO_4$ were evaluated for plant structure and yield components. The results revealed that supplemental K is a prerequisite for modern transgenic cotton grown on poor arid soils, as it ensures sufficient plant growth and development and subsequently increases the seed-cotton yields to considerable levels. However, basal K application alone would not fulfil the cotton yield potential. Splitting the annual dose to 2-4 mid-season side-dress applications significantly improved seed-cotton yield. Nevertheless, a basal K application, followed by four foliar sprays of 2% $K_2SO_4$ during the season resulted in the highest yield, obtaining up to 40% more yield than the non-fertilized control, and 10-15% more than that of the split soil-applied K. These results demonstrate the importance of matching plant K status to the dynamic crop demands for this nutrient, particularly in modern transgenic cotton cultivars.

## Introduction

Cotton (*Gossypium hirsutum* L.) is a world leading fiber crop and Pakistan ranks fourth among cotton producing countries (Indexmundi, 2015) with 12.8 million bales produced during 2014, generating 1.4% of the GDP (Economic Survey of Pakistan, 2014). In arid environments, crop nutrition has always been a key component of high cotton yields (Ahmed *et al.*, 2013; Karim *et al.*, 2016). While nitrogen (N), phosphorus (P) and potassium (K) are key nutrients required in large quantities by all crop plants, the use of K fertilizers for cotton is very low in Pakistan. Nevertheless, K is essential for obtaining high seed-cotton yield and fiber quality (Bennett *et al.* 1965; Mullins *et al.*, 1997; Zhao *et al.*, 2001; Oosterhuis, 2002; Aneela *et al.*, 2003; Sardar *et al.*, 2003; Pervez *et al.*, 2004; Pettigrew *et al.*, 2005).

Cotton genotypes differ significantly in their response to K fertilization (Pettigrew, 2008). The genotypic differences in K-response are probably due to the bigger root system of the more responsive genotypes, enabling faster or more efficient K up-take (Cassman *et al.*, 1989a; Brouder and Cassman, 1990). Furthermore, new high yielding and early maturing cotton varieties demand a significantly high K supply (Baily and Gwathmey, 2007; Pettigrew, 2008; Abaye, 2009; Xia *et al.*, 2013). Cotton has been recognized as very sensitive to K deficiency (Rosolem *et al.*, 2003). Deficiency symptoms occur even in soils that are not considered generally as K-deficient (Cassman *et al.*, 1989b). Potassium deficiency causes low boll weight (Kerby *et al.*, 1985), reduced sugar translocation from leaves (Pettigrew, 1999), low seed-cotton yield and poor fiber quality (Mallarino *et al.*, 1999; Pettigrew *et al.*, 2005). Although it is not a constituent of any plant compound, K plays an integral role in enzyme activation (Usherwood, 2000) involved in numerous metabolic processes.

Potassium availability from soils of arid environments is generally inadequate to fulfil potential crop yields. Light-textured soils are mostly favored for cotton production. However, in addition to the low nutrient availability in these soils, the accessible K is often rapidly leached down below the root zone. Thus, K availability might diminish at the boll setting period, when cotton requirements for this nutrient drastically increase (Halevy, 1976). Hence, supporting a steady K supply through fertilizer application seems critical in order to guarantee sufficient yield levels. Application regimes and methods may have significant impacts on K-uptake in cotton, which is challenged due to its sparse tap root system (Cappy, 1979) and the relatively low plant density in a row (Oosterhuis, 2002). The most common (and low-cost) practice for K administration is pre-planting application of the whole seasonal K fertilizer dose to the shallow soil level (basal application). In cases of K-fixing soils, or rapid nutrient leaching, this dose may be split during the season to several applications, with K fertilizers applied as a side-dressing on the soil surface along the row. The approach of foliar sprays of liquid K fertilizers is a useful deficiency correcting tool (Halevy and Markovitz, 1988), when K soil supply or plant uptake are poor, and plant growth and development are at risk (Pettigrew *et al.*, 2000). Nevertheless, only a few studies have addressed ways to combine soil and foliar K applications in cotton in order to suit an appropriate regime for K fertilization.

In recent years, scientists from the Central Cotton Research Institute (CCRI), Multan, Pakistan, have developed a series of *Bt.*-transgenic modern cotton cultivars, aimed at reducing insecticide use. The objectives of the present study were to determine the adequate K dose required to grow one of these cultivars, *Bt.*-CIM-616, on an arid light soil, to evaluate the effects of a split K application, and to quantify the contribution of additional foliar K applications on seed-cotton yield and its components.

## Materials and methods

The two-year field studies were conducted at CCRI, Multan (30°12'N, 71°28'E and altitude 123 m above sea level) during the 2014 and 2015 cropping seasons. Soil properties were determined at 30 cm depth (Table 1). The experiments consisted of two sets. In set-I, the treatments comprised of $K_0$ (control), $K_1$, $K_1$s, $K_2$, and $K_2$s, focusing on basal or split K applications. Set-II comprised of $K_0$

**Table 1**. Soil properties for the experimental fields at 30 cm depth.

| Soil property | |
|---|---|
| Texture | Silt loam |
| pH | 8.4 |
| Organic matter (%) | 0.52 |
| ECe (dS m$^{-1}$) | 1.71 |
| $NO_3$-N (mg kg$^{-1}$) | 7.0 |
| P (mg kg$^{-1}$) | 8.2 |
| K (mg kg$^{-1}$) | 130 |

(control 1), $K_0$fw (control 2), $K_1$fK, and $K_2$fK, focusing on basal and additional foliar applications. A detailed description of the treatments is provided in Table 2.

Both experimental sets were carried out in a randomized complete block design with four replications. Treatments were laid out permanently and the plots received the same treatment in both years. The soil was prepared with cross wise chiseling followed by cultivation and planking. Seeds (cultivar *Bt*.CIM-616) were manually dibbled in dry conditions on bed-furrows on the third week of April in each year. Water was applied through furrow-flood irrigation. Irrigation, weeding, fungicides and insecticide application measures were kept uniform in all plots.

**Table 2**. A detailed description of treatments.

| Set | Treatment | Seasonal dose | Application regime and methods |
|---|---|---|---|
| | | -----*kg ha*$^{-1}$----- | |
| I | $K_0$ | 0 | |
| I | $K_1$ | 100 | A single basal application |
| I | $K_1$s | 100 | Split: 50% at sowing; the rest at 45 days after sowing (DAS) |
| I | $K_2$ | 200 | A single basal application |
| I | $K_2$s | 200 | Split: 25% at sowing; the rest at 30, 45, and 60 DAS |
| II | $K_0$ | 0 | |
| II | $K_0$fw | 0 | Foliar spray of water at 30, 45, 60, and 75 DAS |
| II | $K_1$fK | 100 | A single basal application and foliar sprays of 2% $K_2SO_4$ at 30, 45, 60, and 75 DAS |
| II | $K_2$fK | 200 | A single basal application and foliar sprays of 2% $K_2SO_4$ at 30, 45, 60, and 75 DAS |

Plant structure and yield components were recorded at maturity. The plant height, nodes, total fruiting points, intact fruits and boll numbers were recorded from five randomly selected plants from

**Photos 2.** From upper left, clockwise: Seed dibbling into the dry bed-soil; furrow flood irrigation after germination; furrow maintenance; rows of young cotton plants. Photos by authors.

each plot. The boll weight was worked out from two randomly selected plants. The data recorded was subjected to Fischer's technique of analysis of variance (ANOVA) and the treatment means were compared at 5% probability level using least significance difference (LSD) test (Steel *et al.*, 1997).

## Results

### Set-I: Effects of dose and K application regime on cotton

Potassium application had a remarkable impact on cotton plant development and structure. A basal K dose of 100 kg $ha^{-1}$ ($K_1$) gave rise to a significant increase (17-21%) in plant height, compared to the control ($K_0$) (Table 3). Doubling this basal dose ($K_2$) resulted in a stronger response, about 35% more than the control. Splitting the seasonal K dose, at both 100 ($K_1$s) and 200 kg $ha^{-1}$ ($K_2$s) significantly enhanced these effects, increasing plant height by 30% and 45% above the control, respectively. The increase in plant height could be attributed to the rise in the number of nodes on the main stem (10-30%), and also to nodal elongation by up to 20% more than the control (Table 3).

Potassium influence on seed-cotton yield was obvious (Fig. 1); seed-cotton yield increased gradually in response to K application dose as well as regime, probably due to some relative improvement in soil K status. While the basal K application of 100 kg $ha^{-1}$ ($K_1$) resulted in a yield increase of 11-22%, a split application of the same dose ($K_1$s) gave rise to a significant yield increase of 16-25%, compared to the control. Nevertheless, a doubled basal dose ($K_2$) enhanced the yield by 20-30%, and, when split into four even applications ($K_2$s), enhanced yield by 30-38%, compared to the non-fertilized control.

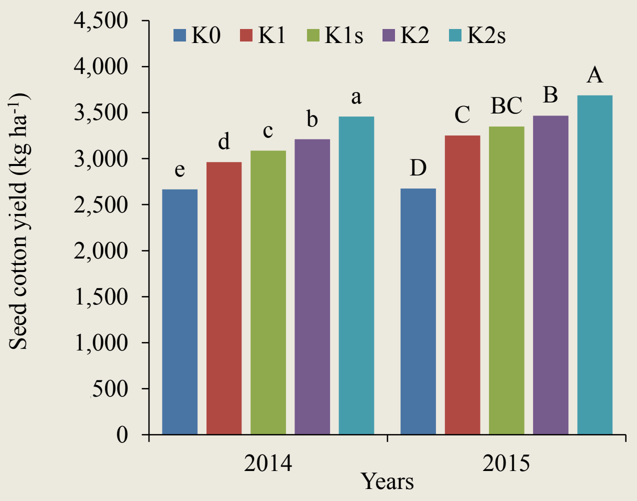

**Fig. 1.** Effects of K application dose and regime on seed-cotton yield in 2014 and 2015. Fertilizer (SOP) was applied as a single basal dose incorporated into topsoil, or evenly split as basal and mid-season side-dressing applications. For detailed description of treatments refer to Table 2. Columns with the same letters do not significantly differ at 5% probability level, using the LSD test.

**Table 3**. Effect of K application dose and regime on plant development at maturity in experimental set-I (see Table 2 for description of treatments).

| Treatment | Main stem height | | Nodes on main stem | | Node length | |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 |
| | -------------cm------------ | | | | -------------cm------------ | |
| $K_0$ | 88.3 | 90 | 31 | 30 | 2.85 | 2.99 |
| $K_1$ | 107 | 105 | 34 | 35 | 3.15 | 3.01 |
| $K_1$s | 115 | 118 | 34 | 37 | 3.38 | 3.20 |
| $K_2$ | 119 | 122 | 35 | 37 | 3.40 | 3.31 |
| $K_2$s | 128 | 131 | 38 | 39 | 3.46 | 3.38 |
| LSD 5% | 7.56 | 12.42 | 2.11 | 4.88 | 0.03 | NS |

The seed-cotton yield increase may be attributed to the improvement in every yield-determining component involved (Table 4). In respect to the non-fertilized control ($K_0$), the number of bolls per plant increased by 16-50%, boll weight increased by 2-10%, and the total number of fruiting points was boosted by 20-30%. Fruit retention was significantly improved, as expressed by

**Table 4.** Effect of K application dose and regime on seed-cotton yield components at maturity in experimental set-I (see Table 2 for description of treatments).

| Potassium Fertilizer | Number of bolls plant$^{-1}$ | | Boll weight | | Total fruiting points | | Total intact fruit | | Shedding | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 |
| *kg $K_2O$ ha$^{-1}$* | | | -------------g------------ | | ---------------------------m$^{-2}$--------------------------- | | | | ------------%------------ | |
| $K_0$ | 25 | 24 | 2.54 | 2.51 | 387 | 391 | 114 | 112 | 70.5 | 71.4 |
| $K_1$ | 29 | 32 | 2.59 | 2.61 | 463 | 479 | 156 | 159 | 66.3 | 66.8 |
| $K_1$s | 30 | 31 | 2.64 | 2.65 | 473 | 487 | 163 | 170 | 65.5 | 65.1 |
| $K_2$ | 32 | 34 | 2.69 | 2.68 | 485 | 498 | 172 | 179 | 64.5 | 64.0 |
| $K_2$s | 33 | 36 | 2.74 | 2.75 | 497 | 509 | 184 | 193 | 63.0 | 62.1 |
| LSD 5% | 2.80 | 3.11 | 0.10 | 0.12 | 8.7 | 23.3 | 11.4 | 14.7 | 3.49 | 3.46 |

the declining fruit shedding rates from about 70% in the control down to 62% in the $K_2$s treatment. Overall, the total number of intact fruit increased by 37-72%. In all yield components, the response was gradual, with a direct linkage to K dose and regime. Thus, the smallest improvements were obtained with the lower basal K input ($K_1$), whereas the best values were recorded in the higher K dose split into four applications ($K_2$s) (Table 4).

### Set-II: The additive effects of foliar K applications on cotton development and yield components

Basal K application fortified with foliar applications of $K_2SO_4$ (2%) resulted in significant enhancement of plant growth and development (Table 5), giving rise to a 20-40% increase in plant height, 7-28% more nodes on the main stem, and 12-15% longer nodes. Excluding node length, growth response to the higher K dose ($K_2$fK) was twice that of $K_1$fK. Consequently, the yields of $K_1$fK and $K_2$fK were 24-27%, and 32-38% higher, respectively, than those of $K_0$fw, the water-sprayed control (Fig. 2).

The influence of the foliar K applications on the cotton yield components (Table 6) was quite similar to those of the split K doses in set-I (Table 4). In respect to the water-sprayed control ($K_0$fw), the number of bolls per plant increased by 19-42%, boll weight increased by about 9-13%, and the total fruiting points boosted by 21-38%. Fruit retention was also improved, as expressed by the declining fruit shedding rates from about 70% in the control down to about 63% in the $K_2$fK treatment. Overall, the total number of intact fruit was increased by 32-52%. Similar to set-I, in all yield components, the response was gradual with a direct linkage to K dose (Table 6).

### Discussion

Potassium is required in large amounts by cotton for normal crop growth and fiber development, with a typical high yielding crop containing about 200 kg K ha$^{-1}$ (Oosterhuis, 2002). Plant K uptake follows a pattern similar to dry weight accumulation, except that K uptake peaks from 2.2 to 5 kg ha$^{-1}$ day$^{-1}$ a few weeks after the start of flowering (Halevy *et al.*, 1987). Cotton is more sensitive to low K availability than most other major field crops and often shows signs of K deficiency on

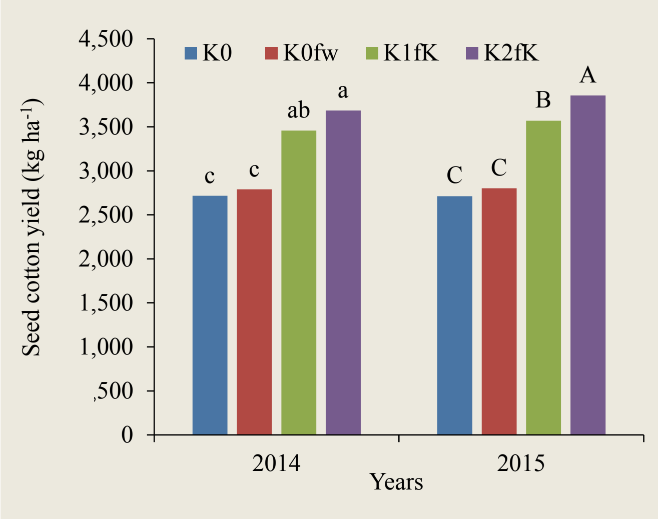

**Fig. 2.** Effect of basal K dose fortified with foliar application of $K_2SO_4$ (2%) on seed-cotton yield at maturity in experimental set-II (see Table 2 for description of treatments).

**Table 5**. Effect of basal K dose fortified with foliar application of $K_2SO_4$ (2%) on plant development until maturity in experimental set-II (see Table 2 for description of treatments).

| Treatment | Main stem height | | Nodes on main stem | | Node length | |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 |
| | -------------*cm*------------- | | | | -------------*cm*------------- | |
| $K_0$ | 97 | 94 | 30 | 29 | 3.23 | 3.25 |
| $K_0f_w$ | 101 | 99 | 31 | 30 | 3.25 | 3.31 |
| $K_1f_k$ | 121 | 124 | 33 | 33 | 3.66 | 3.80 |
| $K_2f_k$ | 132 | 136 | 37 | 38 | 3.57 | 3.60 |
| LSD 5% | 4.99 | 4.62 | 4.69 | 4.75 | 0.31 | 0.54 |

**Table 6**. Effect of basal K dose fortified with foliar application of $K_2SO_4$ (2%) on seed-cotton yield components at maturity in experimental set-II (see Table 2 for description of treatments).

| Potassium Fertilizer | Number of bolls plant$^{-1}$ | | Boll weight | | Total fruiting points | | Total intact fruit | | Shedding | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 | 2014 | 2015 |
| *kg $K_2O$ ha$^{-1}$* | | | -------------*g*------------- | | ----------------------------*m$^{-2}$*---------------------------- | | | | ------------*%*------------ | |
| $K_0$ | 26 | 25 | 2.58 | 2.51 | 391 | 396 | 121 | 120 | 69.1 | 69.6 |
| $K_0f_w$ | 26 | 26 | 2.60 | 2.54 | 401 | 403 | 127 | 124 | 68.3 | 69.2 |
| $K_1f_k$ | 31 | 35 | 2.84 | 2.81 | 487 | 496 | 168 | 174 | 65.5 | 64.9 |
| $K_2f_k$ | 33 | 37 | 2.91 | 2.87 | 503 | 517 | 187 | 189 | 62.8 | 63.4 |
| LSD 5% | 4.7 | 3.2 | NS | 0.072 | 10.2 | 23.9 | 5.7 | 16.4 | NS | 4.1 |

soils not considered K deficient (Cassman *et al.*, 1989b). When soil K levels are insufficient, the cotton crop moves more quickly (earlier) from the vegetative to the reproductive phase (Gwathmey and Howard, 1998; Pettigrew, 1999) resulting in a decline in yield (Pettigrew, 2008). In the present study, cotton plant growth and development, as well as seed-cotton yield, were significantly enhanced by K application, compared to non-fertilized controls. When two doses were examined through basal application, 100 and 200 kg $K_2O$ $ha^{-1}$, plant performance and yield seemed to respond linearly to K dose (Fig. 1). These results provide additional evidence for the critical role of K fertilization for enhancing cotton yields grown on poor arid soils in Pakistan (Ahmed *et al.*, 2013; Karim *et al.*, 2016).

In spite of the significant increase in yield, the efficiency of basal K application is of great concern. Considering the low cation exchange capacity characterizing light soils, the high leaching rate in flooded soils, and the poor K-acquiring ability of cotton root system (Cappy, 1979; Gerik *et al.*, 1987), one may assume that a substantial proportion of the basal K dose would not reach the plant.

Indeed, a further increase in plant development (Table 3) and yield was achieved whenever the basal dose was split (Fig. 1). Applying 100 kg $K_2O$ $ha^{-1}$ as two equal splits, and 200 kg $K_2O$ $ha^{-1}$ as four equal splits produced 3.6% and 7% higher seed-cotton yield, respectively, compared to the full K fertilizer dose applied at sowing. The need for K rises dramatically when bolls are set because developing bolls have a high K requirement (Abaye, 2009; Sekhon and Singh, 2013). It is crucial that K is made available when the plant begins to set fruit. In modern varieties, such as *Bt*.-CIM-616, the length of the flowering period has been reduced from 5-7 to 3-5 weeks, thus the current varieties produce a larger crop during a shorter period of time (Abaye, 2009). Even a high K level in the topsoil may not be adequate for some of the new high-yielding cotton varieties (Cassman *et al.*, 1989a; Oosterhuis, 2002). Therefore, the increasing K requirements during the boll set period can be met by strengthening the basal application with mid-season side-dressing. Silva (1984) showed that a 10% seed-cotton yield improvement obtained through basal K application was further increased by 40% more than the non-fertilized control by splitting the K dose. In fact, mid-season side-dressing with K fertilizers has become a common practice in the 'Cotton Belt' in the US (Oosterhuis, 2002). Despite this, the increase in yields in set-I of the present study was predominantly linked to the basal K dose, whereas the split application provided only a marginal contribution. The cost of multiple K side-dressings during the crop season compared with the benefit in yield might raise economic debates.

Foliar K applications offer the opportunity of correcting deficiencies quickly and efficiently, especially late in the season when soil contribution of K may not be effective or possible (Oosterhuis, 2002). Foliar feeding of a nutrient may actually promote root absorption of the same nutrient (Keino *et al.*, 1999). In the present study, foliar applications of $K_2SO_4$ (2%) gave rise to 24-38% yield increases, as compared to the non-fertilized control, and depending on the basal K dose (Fig. 2). This increase was comparable to that obtained by the split soil applications (Fig. 1). The major effects of soil-applied K were manifested in plant development and subsequent increase in the number of intact fruit, having only a small influence on boll weight (Tables 3 and 4). In the foliar applications, however, boll size increased significantly, while plant structure and other yield components were less affected (Tables 5 and 6). Fruit retention, an important indicator of the cotton plant fitness as well as a yield factor, was similarly improved by soil or foliar K application (Tables 4 and 6). These results are in agreement with previous studies linking a steady K-soil availability with improved plant development and yielding capacity (Mullins *et al.*, 1997; Pettigrew *et al.*, 2005). Supported by recent studies in cotton (Brar *et al.*, 2008; Sawan *et al.*, 2008; Kaur *et al.*, 2011; Dewdar and Rady 2013; Sekhon and Singh 2013), these results also demonstrate the ability of foliar K applications to correct temporary deficiencies directly where and when required, obtaining maximum benefits of soil with supplemental foliar-K applications.

For technical constraints, the two experimental sets were carried out separately, in neighboring fields, and therefore analyzed individually. Nevertheless, results were quite similar in both years. Merging the two sets provided a better view of the results, particularly regarding possible differences between the two approaches, e.g. split soil-applied dose vs. the basal and foliar K application (Fig. 3). The advantage of the second approach is quite obvious; foliar applications of 2% $K_2SO_4$ produced 30 and 40% increases in seed-cotton yield, while the respective split soil-applied doses of 100 and 200 kg $ha^{-1}$ resulted in only about 20 and 33% more yield, compared to non-fertilized controls, respectively. Thus, in addition to being significantly less expensive than the split soil application, the combined basal and foliar K applications provide 10-15% more yield.

In conclusion, supplemental K is a prerequisite for cotton grown on poor arid soils, as it ensures sufficient plant growth and development and subsequently increases seed-cotton yields by considerable levels. However, basal K application alone would not fulfil the cotton yield potential due to the diminishing available K in the soil in relation to the increasing K demands during the critical period of boll set and development. Splitting the annual dose to 2-4 mid-season side-dress applications significantly improved seed-cotton yield. Nevertheless, a basal K application,

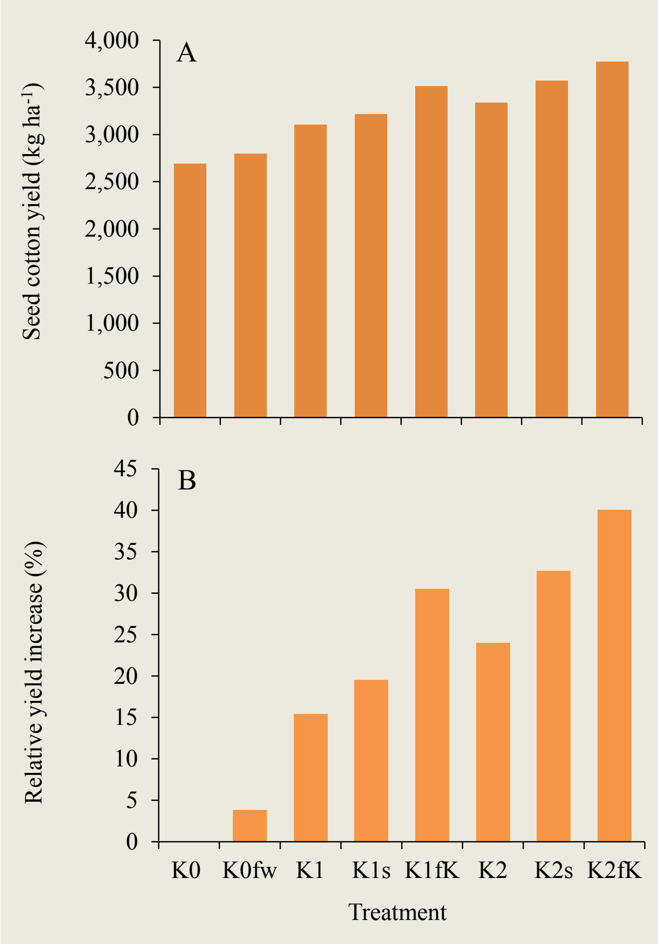

**Fig. 3.** A comparative analysis of the absolute (A) and relative (B) seed-cotton yields of the two experimental sets. Columns represent the mean yearly seed-cotton yield over 2014 and 2015. For detailed description of treatments refer to Table 2.

followed by four foliar sprays of 2% $K_2SO_4$ during the season resulted in the highest yield. These results demonstrate the relevance of matching plant K status to the dynamic crop demands for this nutrient, particularly in modern transgenic cotton cultivars. Further improvements in nutrient use efficiency in cotton would require the consideration of technologies enabling the monitoring of petiole K status during the season (Roberts *et al.*, 1993; Oosterhuis, 2002), as well as more precise delivery of water and nutrients to the plant roots, e.g., fertigation.

## Acknowledgment

The results presented are a part of an International Potash Institute (IPI), Switzerland, funded project entitled “Response of cotton to potassium fertilizer under arid environment in the southern Punjab, Pakistan”.

## References

Abaye, A.O. 2009. Potassium Fertilization of Cotton. Virginia Cooperative Extension, Virginia Tech, Publication 418-025.

Ahmad, R., R.G.M. Hur, E.A. Waraich, M.Y. Ashraf, and M. Hussain. 2013. Effect of Supplemental Foliar-Applied Potassium on Cotton (*Gossypium hirsutum* L.) Yield and Lint Quality under Drought Stress. Pak. J. Life Soc. Sci. 11:154-164.

Aneela, S., A. Muhammad, and M.E. Akhtar. 2003. Effect of Potash on Boll Characteristics and Seed Cotton Yield in Newly Developed Highly Resistant Cotton Varieties. Pak. J. Biol. Sci. 6:813-816.

Bailey, J.C., and C.O. Gwathmey. 2007. Potassium Effects on Partitioning, Yield, and Earliness of Contrasting Cotton Cultivars. Agron. J. 99:1130-1136.

Brar, M.S., M.S Gill, K.S. Sekhon, B.S. Sidhu, P. Sharma, and A. Singh. 2008. Effect of Soil and Foliar Application of Nutrients on Yield and Nutrient Concentration in Bt cotton. J. Res. 45:126-131.

Brouder, S.M., and K.G. Cassman. 1990. Root Development of Two Cotton Cultivars in Relation to Potassium Uptake and Plant Growth in Vermiculitic Soil. Field Crops Research 23:187-203.

Cappy, J.J. 1979. The Rooting Patterns of Soybean and Cotton throughout the Growing Season. Ph.D. Dissertation, University of Arkansas, Fayetteville.

Cassman, K.G., T.A. Kerby, B.A. Roberts, D.C. Bryant, and S.M. Brouder. 1989a. Differential Response of two Cotton Cultivars to Fertilizer and Soil Potassium. Agron. J. 81:870-876.

Cassman, K.G., D.C. Bryant, S.L. Higashi, B.A. Roberts, and T.A. Kerb. 1989b. Soil Potassium Balance and Cumulative Cotton Response to Annual Potassium Additions on a Vermiculitic Soil. Soil Sci. Soc. Amer. J. 53:805-812.

Dewdar, M.D.H., and M.M. Rady. 2013. Influence of Soil and Foliar Applications of Potassium Fertilization on Growth, Yield and Fiber Quality Traits in two *Gossypium barbadense* L. Varieties. Afri. J. Agri. Res. 8:2211-2215.

Economic Survey of Pakistan. 2014. 26-27. Ministry of Finance, Govt. of Pakistan. Available online. http://www.finance.gov.pk/survey_1213.html.

Gerik, T.J., J.E. Morrison, and F.W. Chichester. 1987. Effects of Controlled Traffic on Soil Physical Properties and Crop Rooting. Agronomy Journal 79:434-438.

Gwathmey, C.O., and D.D. Howard. 1998. Potassium Effects on Canopy Light Interception and Earliness of No-Tillage Cotton. Agronomy Journal, 90:144-149.

Halevy, J. 1976. Growth Rate and Nutrient Uptake of Two Cotton Cultivars Grown under Irrigation. Agronomy J. 68:701-705.

Halevy, J., A. Marani, and T. Markovitz. 1987. Growth and NPK Uptake of High-Yielding Cotton Grown at Different Nitrogen Levels in a Permanent Plot Experiment. Plant and Soil 103:39-44.

Halevy, J., and T. Markovitz. 1988. Foliar NPKS Application to Cotton from Full Flowering to Boll Filling. Fertiliser Research 15:247-252.

Indexmundi. 2015. http://www.indexmundi.com/agriculture/?commodity=cotton&graph=production.

Karim, F., J. Iqbal, M. Shabbir, S. Kaleem, and M.Q. Waqar. 2016. Response of Cotton to Foliar and Soil Applied Nutrients under Dera Ghazi Khan Conditions. Journal of Environmental and Agricultural Sciences 7:14-18.

Kaur, P., G.S. Buttar, M. Kaur, and R.S. Sohu. 2011. Effect of Foliar and Split Application of Potassium on Seed Cotton Yield and Fibre Quality of American Cotton (*Gossypium hirsutum* L.). Ind. J. Agric. Sci. 81:838-842.

Keino, J., C.A. Beyrouty, and D.M. Oosterhuis. 1999. Differential Uptake of Potassium by Plant Roots. *In:* Oosterhuis, D.M., and G. Berkowitz (eds.). Frontiers in Potassium Nutrition: New Perspectives on the Effects of Potassium on Crop Plant Physiology. Published Potash and Phosphate Institute and American Society of Agronomy.

Kerby, T.A., F. Adamsand, and R.D. Munson.1985. Potassium Nutrition of Cotton. Potassium in Agriculture. Am. Soc. Agron, Madison. p. 843-860.

Mallarino, A.P., J.P. Bordeli, and R. Borges. 1999. Phosphorus and Potassium Placement on Early Growth and Nutrient Uptake on No-Till Corn and Relationship with Grain Yield. Agron. J. 91:37-45.

Mullins, G.L., C.H. Burmester, and D.W. Reeves. 1997. Cotton Response to In-Row Sub Soiling and Potassium Fertilizer Placement in Alabama. Soil Tillage Res. 40:145-154.

Oosterhuis, D.M. 2002. Potassium Management of Cotton. Potassium for Sustainable Crop Production, 331-346.

Pervez, H., M. Ashraf, and M.I. Makhdum. 2004. Influence of Potassium Rates and Sources on Seed Cotton Yield and Yield Components of Some Elite Cotton Cultivars. J. Plant Nutr. 27:1295-1317.

Pettigrew, W.T. 2008. Review: Potassium Influences on Yield and Quality Production for Maize, Wheat, Soybean and Cotton. Physiologia Plantarum 133:670–681.

Pettigrew, W.T. 1999. Potassium Deficiency Increases Specific Leaf Weights of Leaf Glucose Levels in Field Grown Cotton. Agron. J. 91:962-968.

Pettigrew, W.T., J.C. McCarty, and K.C. Vaughn. 2000. Leaf Senescence-Like Characteristics Contribute to Cottons Premature Photosynthetic Decline. Photosynthesis Res. 65:187-195.

Pettigrew, W.T., W.R. Meredith, and L.D. Young. 2005. Potassium Fertilization Effects on Cotton Lint Yield, Yield Components and Reniform Nematode Population. Agron. J. 97:1245-1251.

Roberts, B.A., T.A. Kerby, and B.L. Weir. 1993. Foliar Fertilization of Cotton in California. p. 64-76. *In:* Murphey, L.S. (ed.) Foliar Fertilization of Soybeans and Cotton. Special publication 1993-1. Potash & Phosphate Institute and Foundation for Agronomic Research, Norcross, GA.

Rosolem, C.A., R.H.D. Silva, and J.A.F. Esteves. 2003. Potassium Supply to Cotton Roots as Affected by Potassium Fertilization and Liming. Pesquisa Agropecuária Brasileira 38:635-641.

Sardar, A., M. Ashraf, and M.E. Akhtar. 2003. Effect of Potash on Boll Characteristics and Seed Cotton Yield in Newly Developed Highly Resistant Cotton Varieties. Pak. J. Biol. Sci. 6:813-815.

Sawan, Z.K., M.H. Mahmoud, and A.H. El-Guibali. 2008. Influence of Potassium Fertilization and Foliar Application of Zinc and Phosphorus on Growth, Yield Components, and Yield and Fiber Properties of Egyptian Cotton (*Gossypium baradense* L.). J. Plant Ecol. 1:259-270.

Sekhon, N.K., and C.B. Singh. 2013. Plant Nutrient Status During Boll Development and Seed Cotton Yield as Affected by Foliar Application of Different Sources of Potassium. American J. Plant Sci. 4:1409-1417.

da Silva, N.M., L.H. Carvalho, E. Cia, E.J. Chiavegato, and J.C. Sabino. 1984. Effect of Split Application of Potassium Chloride in Cotton. Bragantia [online]. 43, p. 111-124.

Steel, R.G.D., J.H. Torrie, and D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw Hill, Inc. Book Co. New York (USA). p. 352-358.

Usherwood, N.R. 2000. The Influence of Potassium on Cotton Quality. Agri-Briefs, Agronomic News No.8 . Spring 2000. Potash and Phosphate Institute, Norcross, GA, USA.

Xia, Y., C.C. Jiang, X. Wang, and F. Chen. 2013. Studies on Potassium Uptake and Use Efficiency of Different Cotton (*Gossypium hirsutum* L.) Genotypes by Grafting. J. Food Agric. Environ. 11:472-476.

Zhao, D., D.M. Oosterhuis, and C.W. Bednarz. 2001. Influence of Potassium Deficiency on Photosynthesis, Chlorophyll Content, and Chloroplast Ultrastructure of Cotton Plants. Photosynthetica 39:103-109.

**The paper "Impact of Potassium Fertilization Dose, Regime, and Application Methods on Cotton Development and Seed-Cotton Yield under an Arid Environment" also appears on the IPI website at:**

**Regional activities/WANA**