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Effect on yield and fiber quality traits of transgenic cotton (*Gossypium hirsutum* L.) by soil and foliar application of potassium

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Abstract

For textile industries of world fiber obtained from cotton is one of essential raw material. It is documented that fiber strength and length decide the quality of yarn to a great extent. However, low uptake of potassium (K) induced a premature senescence in cotton that adversely affects the fiber properties of cotton. As relation behind the improvement in cotton fiber properties and fiber development by balance uptake of K is yet unclear, it hypothesized that better K availability would have the potential to improve cotton yield and fiber quality. Therefore, two years of successive study was conducted to quantify the effect of supplemental foliar-applied potassium with a basal application on cotton (*Gossypium hirsutum* L.) yield and lint quality. The experiment layout was split plot randomized complete block design with four replications and treatments consisted of three potassium rates (0, 100, 150 Kg K ha^{-1}) with two application regimes (soil and soil + foliar), 2% K_2O foliar sprays were applied during peak flowering stages. Results indicated that application of 150 kg ha^{-1} significantly improved plant height (34%), nodes $plant^{-1}$ (29%), inter-nodal distance (27%), bolls $plant^{-1}$ (61%), boll weight (22%) and seed cotton yield (29%). It is concluded that 2% K_2O with soil application of K is more effective tool to staple length while application of 150 kg ha^{-1} can significantly improve yield of cotton.

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Introduction

Adoption of modern cotton varieties is another important factor for K deficiency since the sensitivity of cotton to potassium varies with genotypes. Many reports have indicated that modern cotton varieties with fast fruiting, high yielding or heavy boll load, and early maturity seem to be more susceptible to K limitation than traditional varieties (Oosterhuis, 1990; Tupper *et al.,* 1996). Transgenic cotton varieties with Bt gene seem to be more susceptible than the conventional varieties because of their higher retention of early fruit (Wright, 1998). These transgenic cotton varieties hold a smaller source and a large sink for assimilates than non-Bt cotton, which results in an imbalanced source and sink (Tian *et al.,* 1999). 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 is being considered more susceptible to K deficiency (Rosolem *et al.*, 2003). Deficiency symptoms occur even in soils that are not considered generally as K-deficient (Cassman *et al.*, 1989). This effect of K is important and needs further investigation in view of the fact that the global atmospheric CO_2 concentration is increased and will be possibly doubled at the end of the 21st century (Bolin, 1986). An adequate and continuous K supply throughout the cotton growth period is crucial (Makhdum *et al.*, 2007) for its development and due to its vital role in biomass production (Zahoo *et al.*, 2001), enzyme activation, sucrose transplant, starch and fat/oil synthesis, leaf area expansion, carbon dioxide (CO_2) assimilation (Reddy *et al.,* 2004) photosynthesis; leaf pressure potential; transpiration and water use efficiency (Pervez *et al.,* 2004), boll weight and lint yield (Akhtar *et al.,* 2003). Dramatic increase for K when bolls are set on the plant due to major sink for K (Laffler and Tubertini, 1976).

It is documented that 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). Hence, K nutrition in cotton appears to be indispensable. Potassium requirements of cotton can be met by pre-plant soil application and/or by mid-season side dress applications of K fertilizers. Foliar K applications offer an opportunity to correct the deficiency more quickly (within 20 hrs.) and efficiently, especially late in the season when soil K application is much less effective (Abaye, 2009).

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; Pervez *et al.*, 2004; Pettigrew *et al.*, 2005). Therefore, for increasing its productivity and fiber quality attributes balance uptake of K is highly recommended. Due to the rapid absorption of nutrients plant growth and development occurs smoothly. Foliar feeding is more effective and less costly (Jamal *et al.,* 2006) in most cases.

Therefore, objective of the present study was to determine the adequate K dose for the modern, transgenic cotton cultivar (BTCyto-178) grown on alkaline calcareous soil to evaluate the effects of K application and to quantify the contribution of additional foliar K applications on cotton development, seed-cotton yield and its components and quality traits.

Materials and methods

Experimental setup

In order to investigate the effect of soil and foliar K application on cotton growth and development of transgenic cotton Cyto-178 a permanent layout field experiments were conducted during 2014 and 2015 at the research area of Central Cotton Research Institute, Multan, Pakistan.

The experimental site is situated at latitude 30° 12 'N, longitude 71° 28 'E, altitude 123 meters. The field soil belongs to Miani series. Composite soil samples were collected from plough layer (0-30 cm) before imposition of fertilizer treatments at planting time to the cotton crop. Soil samples were carried out according to the prescribed methods. Soil samples were air-dried, ground and passed through a 2 mm sieve for analysis adopting standard laboratory procedures (Ryan *et al.,* 2001). The field soil belongs to Miani soil series and classified as Calcaric Cambisols and fine silty, mixed Hyperthmic Fluventic Haplocambid and developed in an arid climate of sub-recent flood plains of the Indus delta according to the USDA soil classification system (1998). Data regarding soil analysis revealed that soil texture was silt loam (silt 52%; sand 28%; clay 19%), non-saline (EC_e, 1.8 dS m^{-1}), alkaline reaction (pH_s, 8.2), moderately calcareous ($CaCO_3$ = 5.6%), low in organic matter (0.56%), and contained ($NaHCO_3$-extractable 8.3 mg P kg^{-1}, NH_4OAc-extractable 97 mg K kg^{-1}, DTPA-extractable 0.48 mg Zn kg^{-1}, and HCl-extractable 0.36 mg B kg^{-1}).

Treatments consist of three potassium doses i.e. 0, 100 and 150 K_2O kg ha^{-1} with three 2% K_2O foliar sprays in some treatments according to approved design (Detailed description of the fertilizer treatments) as shown in Table 1. The experimental plot size was 3.5 m × 2.5 m. Treatments were arranged in a split plot randomized complete block design with four replications. The crop was planted in the first week of May at the spacing of 75 cm between rows and 30 cm between plants in the rows. Basal fertilizers at the rate of 250 kg N ha^{-1} as urea, 100 kg P ha^{-1} as triple superphosphate were applied to all experimental plots. 250 kg N ha^{-1} as urea in three splits, i.e., planting, flowering and peak flowering. Gap filling was carried out after 7 DAS to avoid a patchy crop stand to maintain the desired plant population and thinning of seedling was carried out at around 20 DAS. Recommended agronomic practices (hoeing, intercultural, plant protection measures and irrigation etc.) were followed throughout the growth period. The crop was grown up to maturity and cotton plants were harvested from within 1 m^2 for data collection. Cotton was handpicked in each plot and total yield calculated on an area basis.

Following parameters were recorded for statistical analysis.

Plant structure

At maturity cotton plants were harvested from within 1 m^2 area and data on plant structure were recorded by measuring each plant from cotyledon node to the top of the terminal bud and recording number of nodes on the main stem, intermodal distance and plant height

Seed cotton yield and its components

Seed cotton yield was computed on a hectare basis by picking the entire plots manually. A total number of bolls per plant were counted manually Data on boll weight were obtained by dividing the total seed cotton yield with the total number of effective bolls picked from the tagged plants (50 Good opened bolls were picked manually). Boll weight was determined by dividing seed cotton weight by number of bolls harvested. Data on seed index was calculated according to the following formulae:

$$Seed\ Index = Weight\ of\ 100\ seeds\ (g)$$

Cotton fiber characteristics

Cotton fiber characteristics viz staple length, fiber strength, micro-naire value and uniformity index % were determined by High Volume Instrument (HVI), the Fibre Test System manufactured by M/S Zellweger Uster Ltd; Switzerland.

The instrument was calibrated according to the standard method Zellweger, Ltd., (1994). The testing procedure was adopted as reported by ASTM Standard (1997). Ginning out-turn (GOT) is characterized as lint percentage.

The samples of seed cotton were cleaned and the lint and cotton seed were separated using single ruler laboratory gin. The ginning out turn was calculated by the using the formula.

$$GOT(\%) = \frac{Weight\ of\ lint}{Weight\ of\ seed\ cotton} \times 100$$

Seed cotton samples from each experimental plot were taken, weighed, ginned out with a roller machine and GOT was calculated.

Statistical analysis

Statistical analysis, drawing graphs and data computations were made on Microsoft Excel 2007 (Microsoft Corporation, Redmond, WA, USA) and Statistix 8.1 (Analytical Software, Tallahassee, USA).

The least significant difference (LSD) test (Steel *et al.*, 1997) at the 0.05 probability level was applied to test the significance of the treatment means.

Results

Results confirmed that effect of treatments was significant on nodes plant^{-1}, inter-nodal distance, total number of bolls plant^{-1}, boll weight, seed index and seed cotton yield of cotton. It was noted that cotton grown in highest application rate of K (150 kg ha^{-1}) remained significantly better as compared to control for nodes plant^{-1}, inter-nodal distance, total number of bolls plant^{-1}, boll weight, seed index and seed cotton yield. A basal K dose of 100 kg ha^{-1} also gave rise to a significant ($p \leq 0.05$) increase in nodes plant^{-1}, inter-nodal distance, total number of bolls plant^{-1}, boll weight, seed index and seed cotton yield as compared to control. Furthermore, no significant change was noted where soil + foliar application was done for nodes plant^{-1}, inter-nodal distance, total number of bolls plant^{-1}, boll weight, seed index and seed cotton yield as compared to soil application.

Table 1. Treatment Plan

Detailed Description of the Fertilization Treatments		
Treatments	K_2O (kg ha^{-1})	Application Regime
T1	0.0	Control (Soil Application)
T2	0.0	Control (Soil Application + 3 Water Sprays)
T3	100	Full at sowing (Soil Application)
T4	100	Full at sowing (Soil Application + Three 2% K_2O Foliar Sprays)
T5	150	Full at sowing (Soil Application)
T6	150	Full at sowing (Soil Application + Three 2% K_2O Foliar Sprays)

Foliar Sprays = Three foliar sprays of **2%** K_2O during critical growth stages like 30, 60 and 90 Days after sowing (DAS).

Seed cotton yield and its components

Analysis of variance confirmed that application of various levels of K in soil significantly improved the seed cotton yield and its components. However, soil and soil + foliar remained statistically alike to each other for seed cotton yield and its components. A basal K dose of 150 kg ha^{-1} gave rise to a significant ($p \leq 0.05$) increase (61%) in total number of bolls plant^{-1}, followed by 100 kg ha^{-1} that gave increase (30%) as compared to the control. Similarly, application regime significantly increased total number of bolls plant^{-1} as shown in the same figure. Soil + foliar applied K nutrition increased (11%) total number of bolls plant^{-1} with compared to soil applied (alone). Likewise, 150 kg ha^{-1} gave rise to a significant increase (22%) in boll weight on main stem, followed by 100 kg ha^{-1} that gave increase (12%) as compared to the control. However, in highest application of 150 kg ha^{-1} a significant ($p \leq 0.05$) increase of 21% in seed index and 16% in seed cotton yield, followed by 100 kg ha^{-1}.

Lint quality

Statistical analysis confirmed that lint quality attributes i.e. staple length, fiber strength and fiber uniformity affected significantly by the application of treatments. However, soil and soil + foliar differed significantly only for fiber strength. Application of 150 kg K ha^{-1} remained significantly better as compared to 100 Kg K ha^{-1} and control for lint quality. Furthermore, 100 kg K ha^{-1} performed significantly better as compared to control for lint quality attributes. Likewise, soil + foliar application of K differed significantly better as compared to soil application of K for all lint quality attributes.

Maximum increase in staple length (12.5%), fiber strength (13.4%) and fiber uniformity (6.3%) were noted as compared to control where 100 kg K ha^{-1} was applied in soil.

Discussion

In current experiment application of 150 kg K ha^{-1} have potential to improve the yield and fiber quality attributes of cotton. This improvement in yield and quality of cotton fiber might be due to high demand of K that was fulfilled by highest application rate of K. Better intake of K might improve the cellulose content of cotton fiber that improve its staple strength. Waraich *et al.* (2011) who reported that foliar application of potassium significantly increased plant height (cm), nodes $plant^{-1}$ and inter-nodal distance. Results coincide with the results of Mandal and Sinha (2004) who observed significant increase in growth parameters *viz.* plant height, number of primary and secondary branches per plant with the application of NPK in Indian mustard. Dewdar and Rady (2013) study on soil and foliar application of potassium on cotton gave similar trend in cotton growth and development. He found an increase in plant structure, yield and its components and fiber quality.

Awon *et al.* (2012) research findings disclosed that foliar application of potassium during critical growth stages of wheat under stress condition increased plant height and yield. The increase in main stem height resulted because of higher N concentration in leaf tissues through sustained supply of K^+ content in the presence of sufficient availability and soil plant continuum (Oosterhuis, 1990).

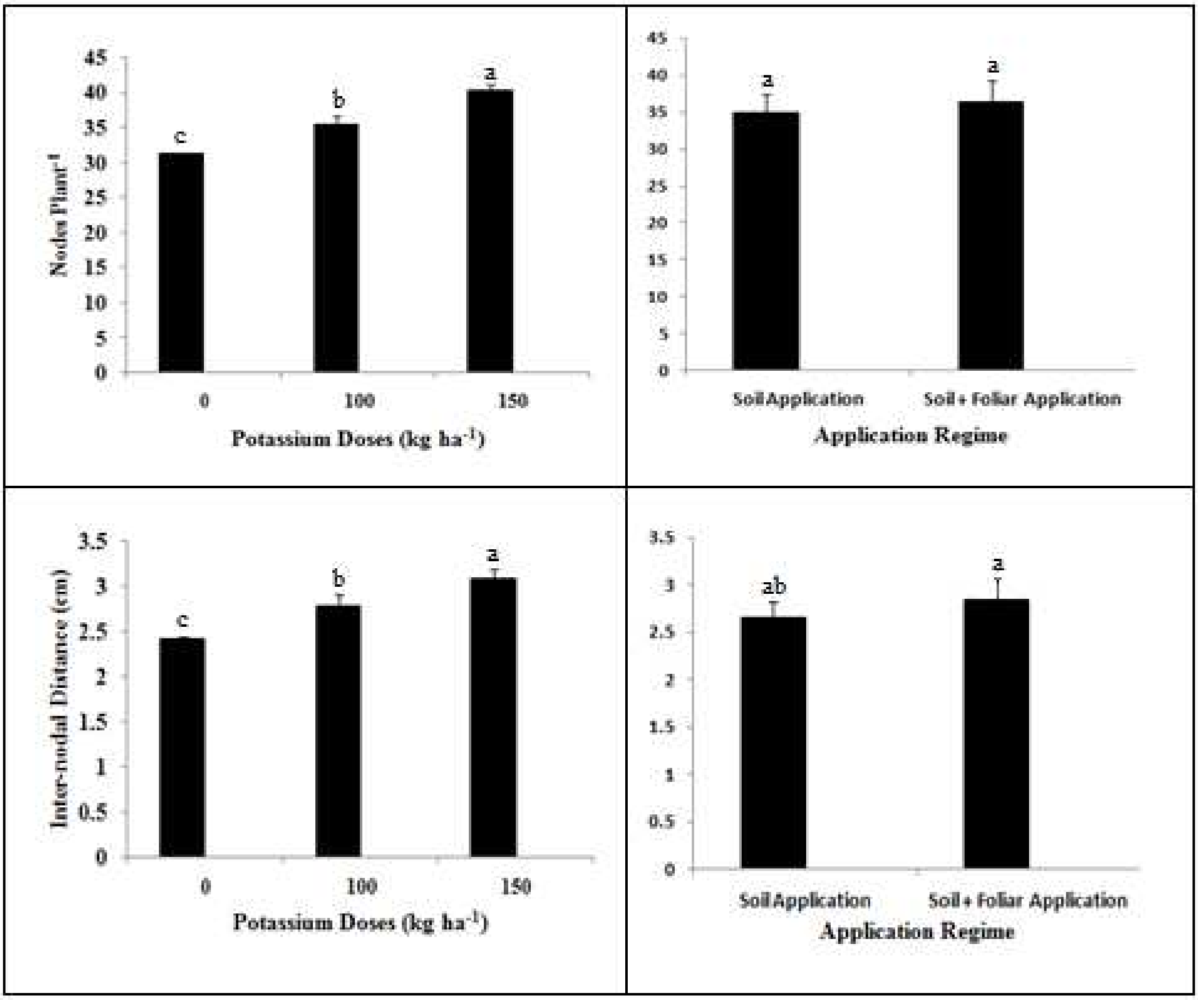

Fig. 1. Effect of different potassium doses and application regime on plant structure of cotton. Data represent the mean ± S.E. of four replications. The Uppercase letters on different bars representing significance ($p \leq 0.05$) of data.

An adequate soil K application is indispensable to obtain considerable cotton yields under the present experimental conditions. All yield parameters which received an RDNP soil application with no, or solely foliar K application, respectively, had the smallest number of bolls per plant, the lowest boll weight, and consequently, the lowest yields. Potassium deficiency results in early abscission of leaves and carbohydrates accumulation in main stem leaves, so the top cotton bolls suffer incomplete development (Gormus, 2002).

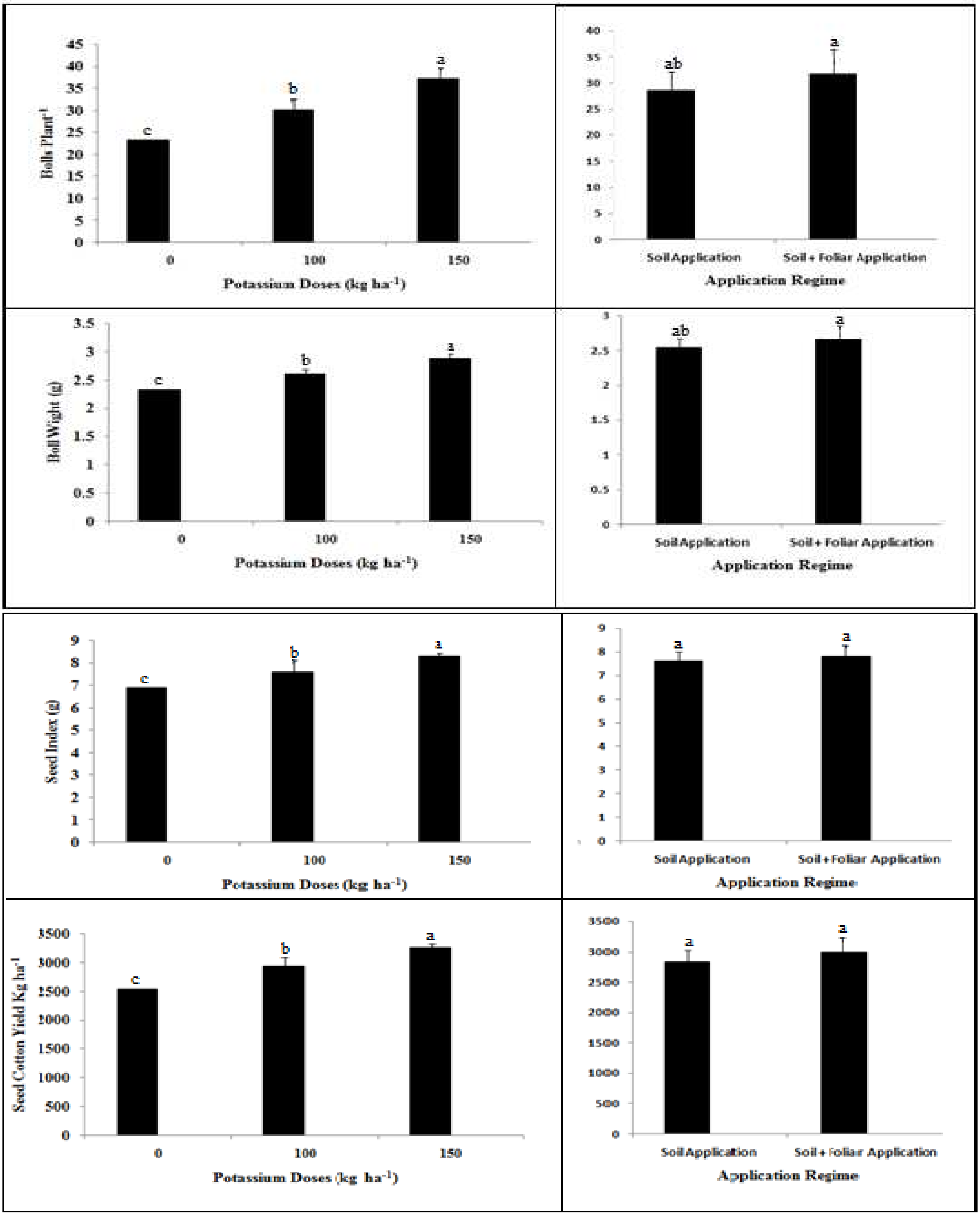

Fig. 2. Effect of different potassium doses and application regime on seed cotton yield and its components of cotton. Data represent the mean ± S.E. of four replications. The Uppercase letters on different bars representing significance ($p \leq 0.05$) of data.

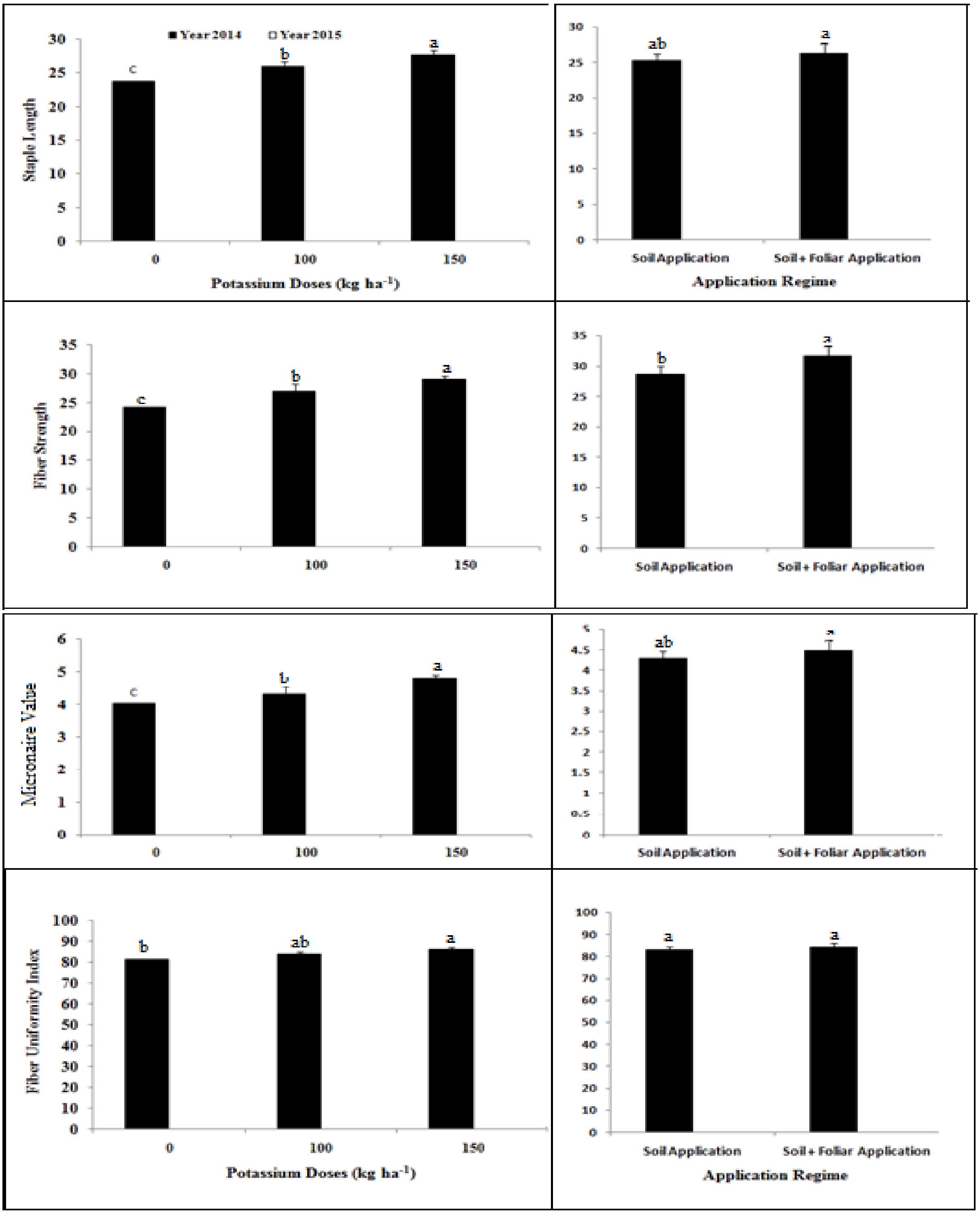

Fig. 3. Effect of different potassium doses and application regime on lint quality of cotton. Data represent the mean ± S.E. of four replications. The Uppercase letters on different bars representing significance ($p \leq 0.05$) of data.

The supply of sufficient K quantities at critical periods, particularly during the boll development stage, resulted in retention of greater numbers of bolls per plant, as compared to the non-sprayed controls (Channakeshava *et al.*, 2013). The higher boll weight is also attributed to additional nutrition due to the foliar KNO3 spray that might have enhanced dry matter translocation and accumulation in bolls (Kumar *et al.*, 2011). These results demonstrate the significance of synchronizing the nutrient supply at different developmental stages using foliar application to enhance growth and consequent higher yields.

Similar results were obtained by Pettigrew *et al.* (2005), Blais *et al.* (2009), Aladakatti *et al.* (2011) and Kumar *et al.* (2011). They found that the treatments of potassium fertilizer applied in two forms (soil addition plus foliar spray) in the appropriate time lead to an increase in boll number and boll weight, and consequently an increase in cotton yield. In the meantime, Pettigrew (2008) stated that the production of less photosynthetic assimilates and reduced assimilate transport out of the leaves to the developing bolls greatly contributes to the negative consequences of potassium deficiencies and are reflected by yield and quality.

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). 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 150 kg K2O ha^{-1}, plant performance and yield seemed to respond linearly to K dose. 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. assume that a substantial proportion of the basal K dose would not reach the plant. Indeed, a further increase in plant development and yield was achieved when three 2% K_2O foliar sprays were done during peak growth stages to meet nutrient thrust. 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*.-Cyto-178, 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). Therefore, the increasing K requirements during the boll set period can be met by strengthening the basal application with mid-season side dressing.

Potassium deficiency restricts saccharide translocation and reduced photosynthesis which negatively impact fiber length and secondary wall thickening therefore badly affecting the resulting micronaire (Zhao and Oosterhuis, 2002).The impact of K-fertilizer is not always visible and consistent in terms of improvement in fiber quality parameters (Bauer *et al.*, 1998) whereas different researchers (Cassman *et al.,* 1990; Minton and Ebelhar, 1991; Pettigrew *et al.*, 1996; Mullins *et al.*, 1999) found that K-unfertilized treatments reduced fibre elongation (3%), fiber length (1%), uniformity ratio (1%), fiber fineness (10%). Bradow *et al.* (2000) also reported that high levels of K were correlated with improved fibre whiteness, fibre maturity, micronaire and decreased fibre yellowness. Malik *et al.* (1988) observed non-significant differences in fibre quality parameters due to added KCl or K_2SO_4. The severe deficiency of K results in unfertilization, embryo abortion and production of undeveloped cotton seeds (motes), which are perceived as the major source of undesirable fibres and imperfections in textiles (Jacobsen *et al.*, 2000). Leffler and Tubertini (1976) found that K^+ is the most abundant cation in cotton fibre, with concentrations exceeding 20 g K^+ kg^{-1} on dry weight basis at 10 to 14 days after anthesis and decreased to about 7g K^+ kg^{-1} at maturity.

Brar and Brar (2004), Kumar *et al.* (2011) and Aladakatti *et al.* (2011) reported that the improvement in fiber length, fiber fineness and fiber strength is attributed to foliar application of K at flowering.

This may be due to that enough supply of potassium during active fiber growth period may cause an increase in the turgor pressure of the fiber, resulting in higher cell elongation and taller fibers at maturity. There have also been more recent reports of foliar-applications of K improving both lint quality and yield (Pettigrew, *et al.,* 1996; Oosterhuis *et al.*, 1990). With the national emphasis on lint quality (Sasser, 1991) and the introduction of high volume instrumentation classification, the positive effect of K on lint quality may be of paramount importance.

In cotton, K plays a particularly important role in fiber development, and a shortage will result in poorer fiber quality and lowered yields (Cassman *et al.*, 1990). Potassium is a major solute in the fiber (single cells) involved in providing the turgor pressure necessary for fiber elongation (Dhindsa *et al.*, 1975). If K is in limited supply during active fiber growth, there will be a reduction in the turgor pressure of the fiber resulting in less cell elongation and shorter fibers at maturity. As K is associated with the transport of sugars (Oosterhuis and Bednarz, 1997), it is likely implicated with secondary wall deposition in fibers and, therefore, related to fiber strength and micronaire.

Waraich *et al.* (2011) concluded that foliar application of potassium at 2% significantly increased ginning out turn (GOT %), fiber micronaire, fiber uniformity (%), fiber length (mm) and fiber strength (g/tex). Ahmad and Rashid (2003) demonstrated the impacts of foliar applied potassium on cotton yield and lint quality parameters. Their studied showed that cotton yield and fiber quality parameters, like fiber micronaire, fiber length(mm), fiber strength (µg/inch) has been improved by applying foliar application of potassium at 1% as a supplemental source under drought stress. Dewdar and Rady (2013) conducted an experiment and observed significant increase in lint percentage, lint index, seed index, fiber length, fiber strength when treated with soil application plus twice potassium foliar sprays during critical growth stages as compared to control (without potassium). Knowles *et al.* (1995) checked the effect of potassium foliar fertilization on Black land cotton and concluded that four foliar sprays of potassium nitrate evidently increases cotton lint yield by 20-30 % as compared to unfertilized plot. Abaye *et al.* (1994) studied the effect of potassium fertilization on fiber quality parameters and cotton yield. They found that fiber quality was increased to a higher extent due to soil application of potassium fertilizer as compared to foliar application of potassium whereas mean boll weight, cotton lint yield were much higher by using foliar application of KNO_3. Gwathmey and Howard (1998) evaluated the comparison of soil and foliar applied potassium nutrition on earliness and cotton lint yield.

Conclusion

A basal application of 150 kg K_2O ha^{-1} as compared to 100 kg K_2O ha^{-1} and control gave significant improvement in the fiber traits and yield of cotton. However, three 2% K_2O foliar sprays application at the reproductive phase (30, 60, and 90 DAS), did not cause any significant change except staple length. It is concluded that foliar application of K on cotton plants improve the staple length while 150 kg K_2O ha^{-1} is the best application rate for improvement in cotton yield and yield related plants attributes.

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