ROLE OF POTASSIUM FERTILIZERS IN PLANT GROWTH, CROP YIELD AND QUALITY FIBER PRODUCTION OF COTTON – AN OVERVIEW

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Abstract

Potassium is essential for the growth and development of cotton crop. It is essential for many of the enzyme systems in the cotton plant and plays a role in reducing the incidence and severity of the wilt disease. Potassium increases water efficiency, affects the speed of almost all plant biological systems, and affects fiber properties such as micronair, length, and strength. Additionally potassium also plays a significant role in photophosphorylation, turgor maintenance, photoassimilate transport from source tissues via phloem to sink tissues, stress tolerance and enzyme activation in plants. Plants translocate the potassium to all parts of plant and in turn yield per plant is increased. The uptake of potassium increases during early boll set with some 70 % of total uptake occurring after first bloom. The most common source of potassium is muriate of potash. Other sources include potassium sulfate and potassium nitrate. To produce one bale of cotton fiber (218 kg), cotton plant requires 20 kg of potassium of which approximately 2-5 kg are being removed by seeds. Potassium fertilization of cotton should receive more attention from the farmers.

Introduction

Potassium is an essential nutrient for all living organisms. It is required in huge amount for normal plant growth and development. Potassium deficiency symptoms appear as yellowish-white mottling to a light-yellowish-green color with yellow spots appearing between the veins. The centers of these spots die, and numerous brown specks occur at leaf tips, around margins, and between veins. The tips and margins break down first and curl downward. As symptoms progress, the whole leaf becomes reddish brown, dries, and becomes scorched and blackened in appearance. Premature dropping of leaves is also the characteristic and may affect boll development in cotton and resulting in bolls not maturing or only partially opening and containing poor quality fiber. Potassium is considered to be an important mineral nutrient element for the plants after nitrogen which needs to be applied in sufficient amount to produce healthy and productive crop (IRRI 2007).

Importance of Potassium for Plant Growth: Potassium plays a foremost role in translocation of carbohydrates, photosynthesis, water relations, resistance against insects and diseases and sustain balance between monovalent and divalent cations (Brar and Tiwari, 2004) and involved in several biochemical and physiological processes that is considered very crucial for plant growth and yield (Marschner, 1995). Additionally potassium also plays a significant role in photophosphorylation, turgor maintenance, photoassimilate transport from source tissues via phloem to sink tissues, stress tolerance and enzyme activation in plants (Usherwood, 2000). Potassium is considered to be a key osmoticum in plants as it provides water relations for plants making them to survive under drought stress. Potassium enhances water uptake of a plant to keep hold of cell turgor required for development and growth of a crop when it accumulates in growth of a plant (De La Guardia and Benlloch, 1980) and stomatal opening and potassium is considered to be mobile in plant and can be translocated against strong electrical and chemical gradients (Brar and Tiwari 2004). Potassium plays a remarkable role in transpiration, stomatal opening and closing and osmoregulation (Cakmak 2005, Millford and Johnson 2002).

Importance of Potassium in Cotton: Potassium as essential macro-element is considered to be an important element for all living organisms which are required in huge amount for normal plant growth and development (Marschner 1995). Likewise boll weight and boll number are related with appropriate increase in potassium (Aladakatti *et al*; 2009; Brar and Brar 2008; Kumar *et al.,* 2011; Wang *et al.,* 2014). Remarkable improvements in cotton yield and quality resulting from potassium input were reported by (Aneela *et al.* 2003, Mullins *et al.* 1991; Pervez *et al.,* 2004; Pettigrew *et al.,* 2005). Cotton plant has indeterminate growing habit and therefore requires high potassium throughout growing season (Fig. 1), therefore potassium uptake has profound impact on cotton plant growth, development, lint yield and fiber quality (Cassman *et al.,* 1990). Potassium is considered a major nutrient supply for cotton production (Mullins *et al.,* 1997). Severe deficiency of potassium in cotton can lead to limited yield through decreased leaf area expansion and CO_2 assimilation capacity and low productivity associated with fiber quality (Bradow and Davidonis, 2000). The developing boll is also a major sink for potassium, especially the seeds (Usherwood, 2000) and potassium is involved in carbohydrate translocation and plant water relations. Potassium deficiency unlike nitrogen deficiency restricts fruit production to a larger extent than vegetative growth (Kirby *et al.* 1985, Pettigrew and Meredith 1997).

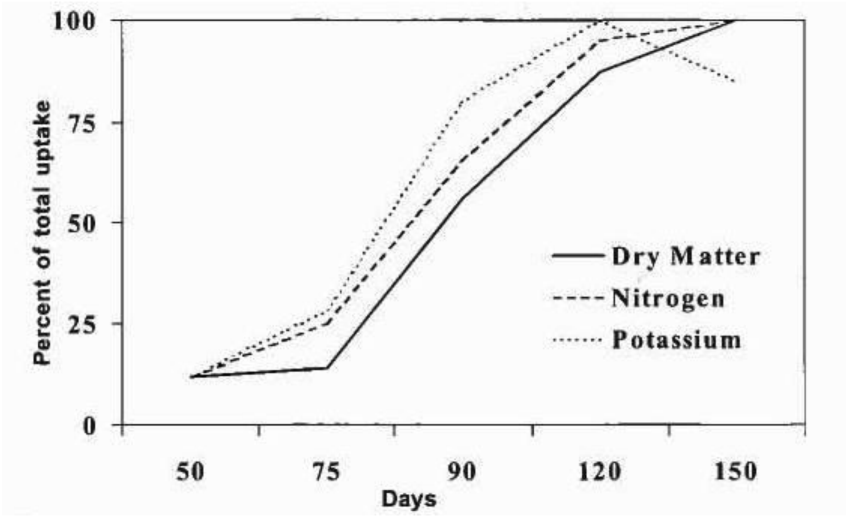

Fig.1. Pattern of Dry matter and Potassium and nitrogen uptake by the cotton crop. (adapted from Mullins and Burmester, 1991)

Potassium Requirements by Cotton: Cotton plant requires large amount of potassium ranging from 3-5 kg ha^{-1} day^{-1}. Potassium taken up by plant represents total quantity that is related to the level of available soil and potassium fertilizer (Kirby *et al.*, 1985) and yield demand of the crop. It has been estimated by (Rimon, 1989) that average mature cotton crop contain 110-250 kg ha^{-1} mostly of which 54% is present in vegetative organs and remaining 46% is in reproductive organs. To produce one bale of cotton fiber (218 kg), cotton plant requires 20 kg of potassium of which approximately 2-5 kg are being removed by seeds (Hodges, 1992; Rimon 1989).

FoliarApplication of Potassium: Foliar feeding of potassium is of great significance for plants because it includes low cost, quick response to plant. Foliar fertilization use only small quantity of nutrients and it provides compensation for lack of soil fixation, but when potassium concentration is found to be very high foliar fertilization may cause foliar burn and can also cause compatibility problems with other pesticides.

El-Ashry *et al.* (2005) reported that negative effects of drought on wheat growth can be diminished by foliar application of potassium. Plants translocate the potassium to all parts of plant and in turn yield per plant is increased. To maximize yield of cotton crop foliar application of potassium may be used to supplement soil application (Pettigrew, 1999, 2008; Sawan *et al.*, 2008). Weir (1998) stated that foliar application of potassium has gained popularity when crop species need the nutrient when it becomes either deficient or needed most. Umar and Bansal (1997) indicated that the best results of groundnut plant were achieved with foliar application of 1% KCl. Howard *et al.* (2000) observed that foliar fertilization may be helpful to correct up potassium deficiencies when root growth and nutrient uptake are restricted. However, where supply of nutrients and soil potassium uptake is insufficient for plant demand foliar application of fertilizer may provide plenty of nutrients for plant growth (Pettigrew *et al.*, 2000). It has been observed that in monsoon season effect of foliar potassium spray was found to be more effective than in winter season because high temperature, humidity favoured foliar potassium spray (El-Fouly and El-Sayeed, 1997). The practice of foliar feeding with plant nutrients gives quick benefits and economizes nutrient element as compared to soil application (Verma and Sahani, 1963).

Mullins and Burmester (1991) indicated that lint yield were enhanced by foliar application of potassium having 116 kg/ha Mehlich -1 extractable potassium whereas opposite results were shown by Bednarz *et al.* (1999) that foliar fertilization when used as a supplemental source did not increase cotton yield to recommended fertility program. Early symptoms of potassium deficiency in cotton can be minimized by foliar application of potassium (Oosterhuis 1995) and may be used to supplement soil application as means to maximize lint yields (Howard *et al.* 1998). Modifying foliar potassium solution chemistry has improved the potassium uptake of cotton (Howard and Gwathmey 1995).

Potassium Deficiency: Severe deficiency of potassium frequently causes various physiological disorders, depressed plant growth and development and reduced cotton yield and fiber quality. Potassium deficiency drastically decreases photosynthesis through a reduction in both leaf area (Huber, 1985) and in net CO_2 fixation (Ozbun *et al.*, 1965). Potassium deficiency is also closely associated with low cholorophyll content, decreased stomatal conductance, poor choloroplast and increased mesophyll resistance (Dong *et al.* 2004). Severe deficiency of potassium in cotton can lead to limited yield through decreased leaf area expansion and CO_2 assimilation capacity and low productivity associated with fiber quality (Bradow and Davidonis 2000).

Joham and Amin (1965) observed that potassium deficiencies in cotton increases vegetative dry matter production and decreased the fruiting index whereas opposite results were reported by Cassman *et al.* (1989) that potassium deficiency resulted in lower plant height, leaf area index, leaf and stem weight and finally the whole plant. Pettigrew and Meredith (1997) found that lower leaf area and plant height were also diminished due to potassium deficiency. However, Pettigrew (1999) also reported that potassium deficiency can change the leaf carbohydrate and water status of cotton plants.

Potassium deficiency typically causes premature termination of growth (Pettigrew, 2008) low boll weight (Kirby *et al.* 1985) and decreased translocation of sugar out of the leaf (Pettigrew, 1999) and decreased in fiber quality and lower yield in cotton (Pettigrew *et al.,* 2005). Severe deficiency of potassium during active fiber growth decreases turgor pressure of fiber to a significant extent that may result in less cell elongation and shorter fiber at maturity. Elevated carbohydrate concentration remaining in source tissues, such as leaves appeared to be part of overall effect of potassium deficiency in reducing the amount of photosynthate available for reproductive sinks thereby causing changes in lint yield and fiber quality in cotton (Pettigrew, 1999). According to Minton and Ebelhar (1991) potassium deficiency causes lint yield reduction and quality indirectly through exacerbating root knot nematode injury.

Potassium Deficiency Symptoms in Cotton: Deficiency of potassium occurs more commonly in cotton crop than other agronomic crops (Kirby *et al.,* 1985). Yellowish-white mottling of leaves which changes to numerous brown specks at the leaf tips, around margins and between veins are most widespread deficiency symptoms in cotton (Marschner, 1995). Leaf tip and margin curl downward finally whole leaf becomes rust coloured, fragile and drops prematurely, stopping boll development which may result in dwarfed and immature fruit. These small bolls are unique symptoms of cotton potassium deficiency. Potassium deficiency symptoms in cotton falls in two category firstly at the bottom of the plant on the lower, older or mature leaves and the other one on young cotton leaves at the top of the plant (Maples *et al.,* 1988; Stromberg, 1960; Weir *et al.,* 1986).

Pettigrew and Meredith (1997) stated that potassium deficiency decreased shortened span length, fiber elongation. 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).

Potassium in Soil: Potassium in soil can be categorized into four different categories due to its availability in plants which are: (i). Lattice or structural potassium, (ii). Exchangeable potassium, (iii). Non-exchangeable potassium, (iv). Soil solution potassium (Syers, 1998). Complete soil solution K can be acquired by plants depending upon nutrient dynamics and total potassium content (Yanai *et al.,* 1996). Deficiency of potassium in soil is closely associated with slow release of exchangeable potassium as compared to plant acquisition (Sparks and Huang, 1985) whereas (Qi and Spalding, 2004) reported that due to high levels of monovalent cations, *e.g.,* Na and NH_4 restrict potassium uptake and eventually results in low potassium content of plants. Short term potassium deficiency is related to spatial heterogeneity and temporal variation in potassium availability mostly because of K transport activity of plant roots, resulting in K- enriched/deficient patches (Ashley *et al.* 2006). Pakistani soils have shown widespread potassium deficiency which presents an alarming situation in the years to come (Akhtar *et al.,* 2003). With increased use of phosphorous and nitrogen fertilizers and due to intensive cropping system in last decade. Potassium deficiency has been considered to be the most limiting factor for increasing rice yield in many places (Dobermann *et al.,* 1996; Dobermann and Fairhurst, 2000; Yang *et al.* 2003). Depletion rate of potassium from Pakistani soil is approximately at 18 kg ha^{-1} $year^{-1}$ (NARC 2003).

Ahmad and Rashid (2003) reported that potassium reserves in Pakistani soils are depleting at an alarming rate. The net potassium depleting rate is 0.3 kg/ ha^{-1} $year^{-1}$. This is mainly due to the negligible use of potassium (0.8 kg ha^{-1} $year^{-1}$) as compared to the world's average use (15.1 kg ha^{-1} $year^{-1}$) while potassium reserves around the world are abundant for agriculture use (Sheldrick, 1985).

Potassium assimilation in Bt and Non Bt Cotton cultivar: Zhang *et al.* (2007) showed the comparison of two Bt cotton cultivars and two conventional cotton cultivars indicated that Bt cotton cultivars had lower dry weight and K uptake than that of conventional cotton cultivars under low potassium condition. Several investigations indicated that Bt cotton cultivars are more susceptible to K deficiency than Non- Bt cultivars (Yukui *et al.,* 2009, Zhang *et al.,* 2007). Nearly 12 elements distribution in leaf, stem and root has been analyzed and results concluded that content of Bt-transgenic cotton in all three organs was lower than that of non-Bt cotton, especially in leaves. Otherwise Bt cotton cultivars respond well to potassium fertilizer application (Yukui *et al.,* 2009).

Bt Cotton and its Economic Importance: From commercial point of view in agriculture Bt cotton was the first to be used as transgenic crops. Gene from soil bacterium *Bacillus thuringenesis* (Bt) has been transferred to cotton genome (Qaim *et al.,* 2003). Bt is a gram positive spore forming bacteria that is found in soil, plant surfaces and in grain storage dust (Qaim *et al.,* 2003). Bt produce toxins known as Bt toxin. Bt toxins are of two types: Cry toxin and Cyt toxins (Qaim and Zilberman, 2003). More than 80 genotypes are present in Bt, most of them produce toxins including exotoxins, enterotoxins and endotoxin (PARC, 2007).

Narayanamoorthy and Kalamkar (2006) investigated Bt cotton cultivation economically viable for Indian farmers. The results of their experiment revealed that cost of cultivation required by Bt cotton was higher as compared to non-Bt crop. However, opposite results were claimed by a seed company that Bt cotton had not reduced the consumption of pesticides. However, Production was found to be higher in Bt than non- Bt cotton. The cost efficiency as well as profit per hectare was found to be higher in Bt than non- Bt. Contradictory results were shown by (Cabanilla *et al.,* 2004) by using estimate percentage difference in yield and cost of production of Bt and non-Bt cotton in other countries of the world. They provided anti assessment of the impact of Bt cotton in China using field trial data supplemented by a general equilibrium model.

Although the growing evidences indicate that Bt cotton is increasing yield and reducing the use of insecticides and increasing production cost in China (Huang *et al.,* 2002; Pray *et al.,* 2001); Mexico (Traxler *et al.,* 2001), USA (Perlak *et al.,* 2001), South Africa (Ismael *et al.,* 2001) the critics of biotechnology are in doubt of its usefulness, especially for small farmers whereas contradictory results were argued by GRAIN (2001) that Bt cotton does not have any positive effect on yield and suggested that bollworms resistant to Bt are already becoming a problem in China.

Exogenous and Soil Application of K in Improving Yield, Growth and Quality Attributes of a Crop: Now-a-days nutrition is considered to be a significant factor to improve yield, growth and quality parameters of cotton. Chemical fertilizers are being used by farmers to meet the nutritional demand required by various agronomic crops, but presently chemical fertilizers are expensive to full fill the requisite demand for crops. In order to overcome these nutritional demands foliar application plays a substantial role to minimize cost.

Waraich *et al.* (2011) reported that foliar application of KNO_3 at 2% markedly increases number of leaves, number of sympodial branches per plant, plant height (cm), number of bolls, ginning out turn (GOT%), fiber micronaire, fiber uniformity (%), fiber length (mm) and fiber strength (g/tex) but boll weight (g) was increased at the rate of 1.5% foliar application of KNO_3.

Ahmad and Rashid (2003) demonstrated the effect of foliar applied potassium on cotton yield and lint quality parameters. They 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 (2013) conducted an experiment and found an increase in number of leaves per plant, total leaf area per plant, dry weight of leaf per plant, seed cotton yield, number of bolls, boll weight, lint percentage, lint index, seed index, fiber length, fiber strength when treated with soil application plus twice potassium foliar spray each at early and peak boll formation as compared to control (without potassium).

Awon *et al.* (2012) conducted an experiment on foliar application of potassium at different growth stages of wheat i.e. tillering, flower initiation and milking under water stress conditions. Results showed that foliar application of potassium at all critical growth stages of wheat (tillering, flowering and milking) improved drought tolerance of plants and notably increased the growth parameters such as plant height, spike length, number of spikelets/spike and yield components like 1000-grain weight, grain yield/plant, number of grains/spike were also improved. Umar *et al.* (1999) observed the Basal and foliar fertilization effects of potassium on yield, quality parameters and nutrient uptake in peanut. Results of field trial showed that foliar application of potassium appreciably increases yield, dry weight, pod number, mature pod, shelling, plant tissue concentration of potassium, K uptake (mg/plant) at 1% foliar application of KCl plus basal fertilization with 50 kg K_2O ha^{-1} while plant tissue concentration of nitrogen, 100 g seed weight, protein and oil content and nitrogen uptake were increased at level of 1% foliar application of K_2SO_4 plus basal fertilization.

Jiffon and Lester (2009) conducted three years consecutive research on foliar fertilization of potassium on Muskmelon on calcareous soil to observe the effects on yield and quality. Results of research showed that using potassium thiosulphate substantially increases yield as compared to control treatment and other potassium sources (KCl, KNO_3, K_2SO_4 , potassium metalosate and monopotassiumphosphate). Fruit quality parameters such as ascorbic acid, β-Carotene, total sugar and soluble solid concentration were increased using potassium metalosate (KM) as foliar spray.

Brar and Brar (2008) evaluated soil and foliar application of different nutrients on yield and nutrient concentration in Bt cotton. Results of experiment showed that foliar application of KNO_3 significantly increases seed cotton yield as compared to soil application and benefit cost ratio were appeared to be 50 times more in foliar application of KNO_3 than soil application of potassium. Coker *et al.* (2009) reported that lint yield was increased up to 40% by applying soil applied potassium under irrigated conditions as compared to non-irrigated conditions. They reported that lint yield was not so much higher with foliar potassium where already soil potassium applications were made according to university of Arkansas recommendations. Keshava *et al.* (2013) showed that foliar application of KNO_3 at 2% plus recommended dose of fertilizers (RDF) (NPK: 150, 75, 75 kg ha^{-1}) basically increases growth parameters and yield parameters of cotton.

Bauer *et al.* (1998) checked the effects of foliar application of potassium on cotton yield and fiber properties of cotton. They reported that lint yield and 50% and 2% span length was higher by application of 112 kg K_2O/ha whereas potassium deficiency lowers fiber length, fiber uniformity, fiber maturity, micronaire and fiber elongation and fiber strength. Dewdar (2013) evaluated soil and foliar application of potassium on cotton crop. They indicated that soil application with addition to foliar spray of K_2SO_4 at 2% each at early boll formation (EBF) and peak boll formation (PBF) stage showed higher number of leaves, total leaf area, dry weight of leaf, cotton seed yield, number of bolls, boll weight, lint percentage, seed index, lint index, fiber length and fiber strength.

Howard *et al.* (1998) performed an experiment on foliar feeding of cotton to evaluate potassium sources, potassium solution buffering and boron. The results of experiment revealed that cotton yield from four potassium sources i.e. KNO_3, K_2SO_4, $K_2S_2O_3$ and KCl were 10 % higher as compared to untreated check and overall yield were 4% higher with KNO_3 and buffering of two potassium source solution to pH 4 resulted in 10% higher yield as compared to check or un-buffered potassium solutions. Howard *et al.* (2000) conducted an experiment for no tillage cotton production to evaluate buffering of foliar potassium and Boron solutions. They reported that buffering of potassium and boron solution increased first harvest and second harvest and total lint yield as compared to buffered or un-buffered solution to pH 6. Mixture of foliar boron and potassium buffered to pH 4 improved total lint yield up to 15.9% as compared to check yield.

Akram *et al.* (2007) performed an experiment of KOH as foliar spray under salt stress to increase the yield and growth of sunflower. KOH was applied at five different levels 0, 0.5, 1.0, 1.5, 2.0 as foliar spray to salt stress and non-stressed sunflower plants. Results of experiment showed that fresh and dry weight of shoot increased when KOH was applied at 1% as compared to control. Aslam *et al.* (2013) conducted research on corn hybrids to study physiological and morphological response of maize by using foliar potassium under moisture stress conditions. Five levels of potassium were used i.e. 0, 50, 100, 150, 200 mg/kg soil. The results indicated that plant height, leaf area, shoot fresh weight, shoot dry weight, relative water content and photosynthetic rate was higher at potassium level of 100mg/kg under drought stress as compared to control where no potassium was applied.

Mehrandish *et al.* (2012) conducted an experiment to evaluate the effects of potassium response to full and deficit irrigation in sugar beet. The results of experiment showed that potassium application at 100 kg/ha clearly increases root yield, shoot yield, dry material of root, sugar yield, pure sugar and impure sugar. Boulbaba *et al.* (2005) reported that highest level of potassium had a depressive effect on chickpea productivity. They indicated that potassium application at lower rate of 50 kg/ha increases nodules, shoot and root biomass in chickpea whereas higher dose of 150 kg/ha potassium lowers biomass production. Uddin *et al.* (2013) conducted an experiment to check the effect of potassium on rice. Four different levels of potassium were used viz. 0, 20, 40, 60 kg K_20/ha. The results indicated that plant height, number of total tillers, number of effective tillers/m^2, length of panicle, number of spikelets/panicle, 1000 grain weight and grain yield were reported to be higher at 40 kg K_2O/ha.

Hosinkhani *et al.* (2013) studied the effects of potassium nutrient on wheat. Results of experiment revealed that foliar application of potassium increases biological yield and grain yield to a significant level at 2 g/litre using potassium. Hussain *et al.* (2011) evaluated different levels of potash fertilizer on mungbean growth and yield response. Five potassium levels were used (0, 30, 60, 90, 120 kg/ha). The results of field trial showed that plant height, number of pod/plants, number of plants/plots and seed yield were increased by using potassium at a level of 90 kg/ha whereas number of branches/plant, 1000 seed weight, protein content of seed was increased at level of 120 kg/ha.

El-Lethy *et al.* (2013) studied potassium effect on wheat plant under salinity stress by using two sources of potassium fertilizers at 25 mg and 150 mg K_2O/kg soil in the form of potassium sulphate. Results showed that application of potassium at 150 mg K_2O/kg soil particularly increases activities of enzymes such as polyphenoloxidase, peroxidase, superoxide dismutase, phenols and soluble sugar and photosynthetic pigments (Cholorophyll a, Cholorophyll b and carotenoids) were also increased at 150 mg K_2O/kg soil. Ghaffar *et al.* (2010) carried out an experiment to determine the effects of potassium application on yield, growth and time of potassium application on sugarcane crop. The results showed that number of tillers/m^2, cane length, cane girth, number of millable canes/m^2, stripped cane yield, sugar yield was palpably increased by applying SOP at 84 kg/ha at sowing plus 84 kg/ha at 90 DAS as compared to where no potassium was applied.

Knowles *et al.* (1995) determined 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) checked the effect of potassium fertilization on fiber quality parameters and cotton yield. reported 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) observed the comparison of soil and foliar applied potassium fertilizer on earliness and cotton lint yield. The comparison showed that foliar application of potassium encourages earliness of cotton and considerably increases cotton lint yield.

Khan *et al.* (2007) conducted a field experiment to check the potassium effect on yield of wheat and rice crop under wheat-rice cropping system. They found that grain yield of wheat and rice were increased by using potassium to higher level up to 13 % and 50% over control respectively whereas number of tillers/m^2, number of spike/m^2, spike length, plant height and 1000 grain weight were much higher using potassium at 60 kg/ha. Weir (1998) determined the effects of foliar application of potassium on cotton quality parameters and cotton yield by applying K_2SO_4 and KNO_3. They reported that both potassium sources increased yield up to 75 kg/ha as compared to control treatment. They also showed that positive response was given to quality parameters by using potassium. Cotton has a huge requirement for potassium and is very sensitive to soil potassium deficiency (Adeli and Varco, 2002). The effects of potassium levels on yield, quality, dry matter weight, root-shoot ratio, reproductive growth to vegetative growth and harvest index of cotton genotypes have been extensively explored (Clement-Bailey and Gwathmey, 2007; Howard *et al.,* 2000, Makhdum *et al.,* 2007; Xia *et al.,* 2013). Potassium fertilization of cotton should receive more attention from the farmers to get high quality cotton crop with optimum yield under various cotton growing regions.

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