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# Nutritional and Physiological Significance of Potassium Application in Maize Hybrid Crop Production

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**Abstract:** Maize is a particular cereal crop which is more affected by variations in plant density than other members of the grass family, due to its low tillering ability, its monoecious floral organization and the presence of a brief flowering period. Different maize cultivars respond differently to K application under varying plant densities, due to different root/shoot ratio, growth rate, crowding stress tolerance, intra-specific competition between plants, K uptake and utilization. Maize cultivars have the ability to withstand high plant density due to more partitioning of assilimilates to shoot as compare to root, resulting in reduction of root/shoot ratio. K application reduces the percent of senescent stalks, lodging and increased crushing strength and rind thickness. There is general consensus that the soils of Pakistan have large capacity to provide K to crop under ordinary conditions, but the increase in the intensity of cropping, excessive use of the tube well water, introduction of the high yielding cultivars requiring high K, increasing use of N and P, could hasten the removal of K from the soils and imbalance the uptake of K in relation to other nutrients. Genotypic and crop species differences exist in response to soil and fertilizer K and non-yield traits such as stalk strength or product quality must be taken into account in K management decisions. K application not only increases grain yield, but also improves quality parameters. K application improves utilization of water, tolerance to drought through stomatal conductance, acceleration in photosynthesis process, water up take through roots. Its application improves leaf area, dry matter accumulation and other allometric parameters. K in combination with N has synergistic influence in uptake, translocation and utilization of nutrients for assimilation in growth and development of final grain yield and its contributing attributes. Normally K deficiency symptoms are usually not conspicuous although grain yield is abruptly decreased (called hidden hunger), but severe deficiency do express symptoms. It is therefore suggested that luxuriant application of K is inevitable for getting successful and maximum production from maize hybrids.

**Key words:** Maize hybrids, K application, nutritional and physiological significance, yield and its attributes

## INTRODUCTION

Maize (*Zea mays* L.) is an important food and feed crop of the world and is often referred as “the king of grain crops”. It ranks third in world production after wheat and rice and is an important cereal crop of Pakistan (Bukhsh, 2010). It is grown extensively with equal success in temperate, subtropical and tropical regions of the world. It forms major dietary part of the millions of the people in the form of bread, cake and porridge in many parts of the world Asia, Africa and America (Bukhsh *et al*., 2003). Besides being an important food grain for human consumption, maize has also become a major component of livestock and poultry feed (Khan and Gill, 1991; Witt and Pasuquin, 2007).

In recent years a large quantity of corn has been used in the manufacturing of shortening compounds, soaps, ammunition, varnishes, paints and similar other products (Martin *et al*., 1975), whereas the by-product seed cake is a valuable component of livestock feed (Ahmad *et al*., 2007 ). Maize oil is used in cooking, bakery products, oleomargarine, salad dressing and pharmaceutical. Maize starch is used for producing bio-fuel (as ethanol) after its fermentation (Rajoo, 1998), making plastics, cellophane, photographic films, dying of clothes, manufacturing of paper, paper boards and tanning of the hides. It is also utilized for getting the important industrial by-products such as glucose, flakes, custard, jelly and energile (Bukhsh *et al*., 2011a).

A maize plant thrives best in subtropical regions where summers are mild. Because of its higher biological efficiency (i.e., maximum increase in yield achieved per kg fertilizer applied) and extremely wide environmental adaptability it can grow without irrigation in regions with as little as 250 mm and in areas with as much as 5000

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mm of rainfall at sea level to 4000 m altitudes in the Islands of Andes (Duncan, 1975). Maize is originally a plant of tropical South America but during the course of development and even before the arrival of Columbus, the Americans Indians had developed a wide range of varieties adapted to local conditions of Canada (Chaudhry, 1983).

At present in Pakistan, diverse maize genotypes, i.e. single cross and double cross hybrids, synthetics and composites are being grown. These genotypes respond differently to various agro management practices especially plant density and nutrition management. This variable response is mainly due to differences in relative maturity (Farnham, 2001), plant morphology (Benga *et al.*, 2001), vertical leaf area profile (Valentinuz and Tollenaar, 2006), grain filling duration (Echarte *et al.*, 2006), intra-specific competition in maize plants (Maddonni and Otegui, 2006), prolificacy (Boris *et al.*, 2004), plant growth rate (Echarte *et al.*, 2000; Maddonni and Otegui, 2004), crowding stress tolerance (Tollenaar and Lee, 2002), sink capacity (Borras and Westgate, 2006; Gambin *et al.*, 2006), K uptake, accumulation and utilization (Farina *et al.*, 1983) of different maize hybrids. These genotypes have the ability to withstand high plant density due to more partitioning of assimilates to shoot as compared to root (Herbert *et al.*, 2001) resulting in reduction of root/shoot ratio (Siddique *et al.*, 1990). There are chances of lodging of plants due to less allocation of assimilates to roots. K application reduces the percent of senescent stalks, lodging and increased crushing strength and rind thickness (Arnold *et al.*, 1974).

The world wide experience shows that more than 50% of the increase in crop production yields is due to fertilizers (Braun and Roy, 1983). On an average, the findings of FAO showed that 1 kg of nutrients ($N_2+P_2O_5+K_2O$) produces around 10 kg cereal grain (FAO, 1981). Potassium (K), one of these three primary nutrients, is absorbed by plants in larger quantities than any other element; expect N (Krauss, 1997). K plays a vital role as macronutrient in plant growth and sustainable crop production (Marschner, 1986; Bukhsh, 2010). It maintains turgor pressure of cells which is essential for cell expansion. It helps in osmo-regulation of plant cell, assists in opening and closing of stomata (Mengel and Kirkby, 1987). It plays a key role in activation of more than 60 enzymes (Tisdale *et al.*, 1990). Its application has primitive effect on growth and development (Brar and Singh, 1995) and grain yield in maize (Davis *et al.*, 1996; Bukhsh *et al.*, 2008). It not only affects the transport of assimilates but also regulates the rate of photosynthesis in maize. It is known for its interaction both antagonistic and synergistic with essential macro and micro nutrients (Dibb and Thomson, 1985). K addition increases its tissue levels in plants and about 80-90% of K absorbed by the plants is found in straw (Rice Production Manual, 1967). K is recognized important for efficient N utilization and have a fairly consistent effect on lowering tissue concentration of Ca and Mg (Terman *et al.*, 1975). An adequate supply of K confers drought tolerance and frost resistance in plants (Coranzzina *et al.*, 1991; Jhonson, 1984; Kemmler and Krauss, 1989). It has been found that foliar application of K has increased quality and yields of maize (Barel and Black, 1979; Giskin *et al.*, 1984; Giskin and Efron, 1986).

There is general consensus that the soils of Pakistan have large capacity to provide available K to crop under ordinary condition most probably due to dominance of illite soil clay minerals (Ranjha *et al.*, 1990; Bukhsh *et al.*, 2008), but the increase in the intensity of cropping (Dobermann *et al.*, 1996a, 1996b), substantial removal of straw from the field (Jiyun and Zhang, 1999), excessive use of tube well water and introduction of high yielding varieties in various cropping systems (Tiwari, 1985; Regmi *et al.*, 2002; Gami *et al.*, 2001; Mohsen, 2007; Yadvinder *et al.*, 2005) have resulted in considerable drain of soil K reserves and crops are becoming responsive to K fertilization. Thus, maize requirement of K is as high as that of N and for about 6 metric tones production, maize removes 120 kg N, 50 kg P and K hectare$^{-1}$ from soil. It may have biological demand for K with uptake of up to 5.2 and 3.7 kg K ha$^{-1}$ day$^{-1}$, respectively during peak time (White, 2000). Young maize plants take more K, by heavy K application, but this uptake does not reflect in terms of grain yield (Rehm and Lamb, 2004; Kaiser *et al.*, 2005). Maize takes up to 38% of the total K for the whole growing season, during 38 to 52 days after sowing (Hanway, 1962; Rehman *et al.*, 2008).

In Pakistan, K status of soils is rapidly decreasing at a distressing rate. The net K draining rate is even steeper i.e 0.3 kg/ha/year. This may be due to the negligible (0.8 kg/ha/year) use of K in Pakistan as compared to world average K use (15.1 kg/ha/year) (Ahmad and Rashid, 2003; Bukhsh *et al.*, 2010).

## Potassium application in maize hybrids

**Characteristics of maize hybrids/genotypes:** Modern maize cultivars respond to K application differently due to difference in its uptake, translocation, accumulation, growth and utilization (Nawaz, 2006; Nawaz *et al.*, 2006; Tsai *et al.*, 1996; Minjian *et al.*, 2007). The K-efficient phenotype is a complex one comprising a mixture of uptake and utilization efficiency mechanisms.

Exudation of different organic compounds helps to release K even from non-exchangeable sites. This is one of the mechanisms to improve K uptake efficiency. Hybrids efficient in K uptake may have a larger surface area of contact between roots and soil and increased uptake at the root-soil interface to maintain a larger diffusive gradient towards roots. The main mechanisms underlying K utilization efficiency are (i) better translocation of K into different organs, (ii) better capacity to uphold cytosolic $K^+$ concentration within optimal ranges and (iii) increased capacity to substitute $Na^+$ for $K^+$ are the main mechanisms underlying K utilization efficiency (Rengel and Damon, 2008).

K inefficient hybrids had reduced harvest index under deficient K supply. They had the capacity to tolerate low concentrations of K in shoot tissue where K supply was deficient was also important in determining K efficiency for grain yield. On the other hand, K-efficient hybrids have the potential to improve the efficiency and sustainability of cereal cropping systems (Damon and Rengel, 2007; Bukhsh, 2010).

Efficient plant cultivars could have better Fertilizer Use Efficiency (FUE) (Epstein and Bloom, 2005) and hence may reduce input cost and conserve environment (Baligar *et al*., 2001; Rengel and Damon, 2008). High plasticity (Sparlangue *et al*., 2007; Breeze and Milbourn, 1981), higher grain yield and stability of harvest index, are the main characteristics of these cultivars, because of genetic yield improvement attributable, in part, to increase partitioning of dry matter to the cob during bracketing silking (Echarte *et al*., 2000; Pettersson and Jensen, 1983). K having the highest concentration in silk further significantly improves the partitioning of dry matter to cob, regulates proteins and adjusts metabolic processes, finalizing in higher yield (Ashley *et al*., 2006). Growth rate studies under different conditions of K restraint indicated that with few exceptions, strong positive correlations between ranks accorded cultivars on the basis of influx kinetics and those based upon growth rates (Glass and Perley, 1980). Plants in solutions without K showed no marked shifts in dry matter accumulation between plant parts. The root $shoot^{-1}$ ratio remained close to that for control plants, except during the recovery, when there was decrease in ratio. While this yield improvement response to K fertilization on low K testing soils is a fairly uniform response, there can be genotypic variation for this response. The more K responsive genotype was (Cassman *et al*., 1989) subsequently shown to produce a more extensive root system than the less $K^+$ efficient genotype (Brouder and Cassman, 1990). Therefore, the genotypic differences in $K^+$ response are probably because of the fact that more $K^+$ responsive genotypes were able to take up $K^+$ at a greater rate or more efficiently because of a bigger root system. Genotypic differences for $K^+$ uptake and use efficiencies have also been detected in other crops. Maize cultivars were demonstrated to differ in $K^+$ uptake efficiencies (Allan *et al*., 1998); with the more efficient $K^+$ uptake hybrid was also being the highest yielding.

Varga *et al*. (2004) reported that prolific maize cultivars responded more favorably than non-prolific cultivars to high-input cropping systems (including additional $K^+$ fertilization), primarily by increasing grain weights and yield. Although a $K^+$ deficiency tolerant maize hybrid produced more dry matter and an increased number of lateral roots than a $K^+$ deficiency sensitive hybrid, the sensitive hybrid actually possessed longer taproots (Minjian *et al*., 2007).

There can be many physiological aspects where can genetics can intercede and lead to the overall variability among genotypes in the response to $K^+$ fertilization. These physiological aspects include: (1) root morphology; (2) root hairs; (3) root exudates; (4) $K^+$ release from un-exchangeable pools; (5) kinetics of $K^+$ uptake; (6) translocation; (7) substitution and (8) harvest index (Rengel and Damon, 2008). The first five physiological traits listed are involved with $K^+$ uptake efficiency, while the later three traits are involved in $K^+$ utilization efficiency. Geneticists and breeders might target to produce more nutrient-use efficient breeding lines (Bukhsh, 2010). It has been observed that K application up to a certain level gives maximum yield and beyond this dose has a suppressive effect on growth, yield and other related parameters, in addition to this; it becomes unprofitable (Iqbal, 1998; Lloveras *et al*., 2001) and needs subsidy for its application (Heisey and Mwangi, 1996).

## Physiological/Nutritional attributes

**Potassium uptake by roots:** Considerable prior research has addressed the mechanisms of how K is absorbed by plant roots. Fundamentally, K up take in plants is bi-phasic; involving two mechanisms; low-affinity $K^+$ uptake and high-affinity $K^+$ uptake. The low-affinity $K^+$ uptake can be considered as a passive influx of $K^+$ down an electrochemical gradient is using inward rectifying K channels. As far as high high-affinity $K^+$ uptake involves an energy-dependent (ATP) inward $K^+$ pump against an electrochemical gradient usually in combination with an outflow of either $H^+$ or $Na^+$.

The total amount of K absorbed by the crop during the growing season depends upon the crop species being grown, the amount of native soil $K^+$, the amount of fertilizer $K^+$ applied, $K^+$ availability in the soil, the environmental conditions during the growing season and the management practices employed (Eakin 1972; Mengel and Kirkby, 1987; Mullins and Bursmester, 1998). In maize majority of $K^+$ accumulation occurs before silking (Hanway, 1962; Karlen *et al*., 1988).

**Potassium functions in stomatal conductance and photosynthesis:** After uptake of K in plants, it is involved in many physiological and biochemical reactions, while on other hand $K^+$ and sucrose both serve as the major osmoticums for rising osmotic potential in open guard cells with malate and $Cl^-$ working as the major counterions (Talbott *et al*., 1998). In guard cells, $K^+$ uptake is facilitated by $K^+$-specific uptake channels and is associated with proton extrusion into the apoplast (Hoth *et al.*, 1997; Triboulot *et al.*, 1997).

During day stomatal opening is thought to be a two phase process (I) with $K^+$ promoting early in the day and (ii) then giving way to sucrose as the principle driving osmotic force around midway (Talbott and Zeiger, 1996). On account of this close cooperation between $K^+$ guard cell concentration and stomatal aperture, $K^+$ concentration in leaf in case of deficiency can lead to decreased stomatal conductance. Consequently, it leads to decreased photosynthesis rate/unit leaf area (Bednarz *et al.*, 1998; Huber 1985; Longstreth and Nobel, 1980; Pier and Berkowitz, 1987; Wolf *et al.*, 2006). However, this decreased stomatal conductance only partially accounts for the photosynthetic decline observed with lower $K^+$ levels.

Sometimes, non-stomatal components help to reduce photosynthesis, especially when the deficiency becomes extreme (Basile *et al.*, 2003; Bednarz *et al.*, 1998; Huber 1985). In case of extreme deficiency, non-stomatal or biochemical factors, become prominent for decreased photosynthesis. This limitation under low $K^+$ conditions is partially associated with chloroplast inner membrane. ATPase that sustains the high stomatal pH needed for substantial energy conversion from sun light to chemical energy by sending protons out of the stroma in to the cytosol, while allowing $K^+$ flux in to the stroma (Berkowitz and Peters, 1993).

The transport of photosynthetic assimilates away from source tissue via the phloem is also reduced in extreme K deficiency conditions (Ashley and Goodson, 1972; Mengel and Haeder, 1977; Mengel and Viro, 1974). This restriction on the transport of photosynthates can lead to an accumulation of sugars in the leaf tissue of $K^+$-deficient plants (Bednarz and Oosterhuis, 1999; Huber, 1985; Pettigrew, 1999). Generally, the hexose sugars, such as glucose and fructose accumulate rather than sucrose (Huber, 1985).

$K^+$ also serves in supporting plant water relations and cell expansion. K is the major inorganic osmoticum in the phloem and thus is integral in the maintenance of turgor pressure for growing tissues, which are chiefly supplied by the phloem (Mengel, 1998).

**Potassium role in growth and development metabolism:** While considering the cumulative effects of many physiological reactions, $K^+$ has significant role in plant growth and development. One of the most significant consequences of K deficiency reflects in reduction of plant stature (Cassman *et al.*, 1989; Ebelhar and Varsa, 2000; Heckman and Kamprath, 1992; Mullins *et al.*, 1994; Pettigrew and Meredith, 1997). This reduction is related with reduction in leaf area. Reduction in leaf area ocurs both through reduction in number of leaves per plant and individual size of leaves (Jordan-Meille and Pellerin, 2004; Pettigrew and Meredith, 1997). Same situation was observed by Jordan-Mille and Pillerin (2004). However, specific leaf weight was increased with $K^+$ deficiency (Pettigrew, 1999; Pettigrew and Meredith, 1997). Less leaf area due to K deficiency may lead to an increased concentration of cellular components, carbohydrates and/or nutrients over a given unit of leaf area compared with leaves with adequate $K^+$ levels (Pettigrew, 2008; Bukhsh *et al.*, 2010).

All combinations of less (i) leaf area, (ii) less solar radiation interception and reduced photosynthesis per unit leaf area under insufficient $K^+$ levels lead to a reduction in the total photosynthetic assimilate pool produced in the plants (leaves). In addition to this, this reduced photo assimilate production with the restricted assimilate transport from the leaves results in a smaller total assimilate supply available for the sink tissue for $K^+$-deficient plants (Bukhsh *et al.*, 2011a). This reduced assimilate supply under a $K^+$ deficiency will ultimately diminish the yield and quality produced by those plants (Pettigrew, 1999).

**Potassium and water economization:** K is essentially involved in the water economy of the plant (Arnon, 1975; Ebdon *et al.*, 1999). It is well established fact that plants adequately supplied with K can utilize the soil moisture more efficiently than K- deficient plants (Mengel and Forster, 1973; Mahmood *et al.*, 1999). By active uptake of K and its accumulation in the cell, water moves in and increases the turgor pressure in the cell. In the fast growing tissues of young plants K is indispensable for obtaining optimum cell turgor which in turn is required for cell enlargement (Mengel and Kirkby, 1982; Mahmood *et al.*, 2000). In fact, there is involvement of K in “osmoregulation”, i.e. adjustment biophysical role (Beringer and Trolldenier, 1978; Lauchli and Pflunger, 1978; Morgan, 1986). Thus it is comprehensible that K plays a chief role in plant tolerance to moisture stress.

In dry soils, bulk $K^+$ content is normally higher, but mass flow and diffusion are constrained (Sieffert *et al.*, 1995; Vetterlein and Jahn, 2004; Kuchenbuch *et al.*, 1986). The negative effects of drought on $K^+$ transport in soil are likely to be more significant than increases in K and therefore these environmental conditions lead to reduced availability of the nutrient (Liebersbach *et al.*, 2004; Kuchenbuch *et al.*, 1986; Sieffert *et al.*, 1995). Increasing bulk density tended to increase K influx because the volumetric water content increased when the gravimetric water content was kept constant (Kaselowsky *et al.*, 1995).

Mild wilting conditions had a stimulatory effect of K on water induced proline accumulation. Marked differences in proline accumulation due to wilting, was observed in different genotypes (Mukherjee, 1980). Use of K uptake, as an index for screening genotypes for drought tolerance, may be possible in future (Raymond and

Smirnoff, 2001; Bukhsh *et al*., 2011b). Proline accumulates in maize root tips, under water stress conditions, where it provides a major part of osmotic adjustment in the meristem at low water potential (Voetberg and Sharp, 1991; Verslues *et al*., 1998).

K fertilization significantly improved the retention of water in the plant tissues even under conditions of severe water stress (Hunter *et al*., 1970). During the periods of water stress, higher supplies of K nutrition in maize may increase plant production (Premachandra *et al*., 1991). Plants having substantial K under normal irrigation usually have lower transpiration rate than that of those plants which are lacking K (Beringer and Trolldenier, 1978; Patel *et al*., 1985). The possible reason might be the ability of the plants to regulate the opening and closing of their stomata efficiently. To achieve the anti-parallel direction of $K^+$ fluxes between these cells during stomatal movement, plasma membrane of subsidiary cells and guard cells has to be inversely polarized (Majore *et al*., 2002). During ABA (Abscisic acid) induced closure, the direction of $K^+$ transport in subsidiary cells and guard cells does not seem to be grounded solely on the cell type specific ABA regulation of $K^+$ channels (Wolf *et al*., 2006).

The pore spaces of the soil are filled with water due to high rainfall or heavy irrigation and poor soil drainage. Oxygen supply is low and anaerobic conditions prevail (at least temporarily). In this case the respiration of plant roots is reduced and nutrient uptake decreased. Plants can compensate despite restricted root activity, by adding high amounts of K (Mengel and Kirkby, 1980; Mengel, 1985; Nelson, 1978).

When small seedlings are lacked of $K^+$ their growth rate declined immediately and after about three weeks only half of the growth rate of those seedlings were well supplied with $K^+$ (Scherer *et al*., 1982; Schroeder, 1979). In the tops of the seedlings without $K^+$ supply showed that accumulation of carbohydrates is a growth process itself and phtotsynthesis and translocation of phototsynthates was not influenced by deficiency of $K^+$.

With the expansion of the meristematic cell, growth starts. This expansion is influenced by phytohormones especially by indole acetic acid. They directly work on ATPases (Schubert and Matzke, 1985) which is an indispensable enzyme of the plasma-lemma and which plays an important role in ion uptake and growth (Poole, 1978; Leonard, 1984). These ATPase are also known as a proton pump since the hydrolyzation of ATP into $ADP^+$ inorganic phosphate is linked with the splitting of a water molecule into $H^+$ and $OH^-$ of which the $H^+$ is released into the apoplast of the cell. This process makes the apoplast acidic and the cytoplasm alkaline and further it develops an electrical gradient between the apoplast and the cytoplasm. $H^+$ released into the apoplast might substitute $Ca^{2+}$ by $H^+$ bridging carboxylic groups of pectinates. The acidic pH in the apoplast starts different hydrolyses which beak up glycosidic bonds of the cell wall material (Hager *et al*., 1971). This process as well as the substitution of $Ca^{2+}$ by $H^+$ finalizes in to the cytoplasm and since the cell walls are softening of the cell wall material. The simultaneous uptake of ions and sucrose into the cell wall develops up an osmotic potential which sucks water into the cytoplasm and since the cell walls are loosened the cell can be expanded considerably as its walls are loose. This cell expansion is the first step of growth; then cell division is initiated. Both mechanisms are the main components in meristmatic growth (Munson, 1968).

**K and N synergistic influence on plant growth:** A lot of previous experience has shown that N and K influence plant growth in a synergistic way (Fridgen and Varco, 2004). Both of these elements should be present in substantial and balanced quantities for proper crop growth (Mengel, 1989; Stromberger *et al*., 1994). K uptake into the cell may contribute to the osmotic potential of the cytoplasm, which is a basic requirement of the osmotic water uptake (Mengel and Arneke, 1982; Leigh, 1989).

Uptake of K into the cytoplasm reduces its negative potential to a depolarization of the plasma-lemma and therefore has a triggering effect on the ATPase. K is taken up in large quantity and helps considerably to the depolarization of the membrane and thus to a satisfactory ATPase activity (Leigh, 2001). In its consequence, only the permanent supply of the meristematic tissues with K guarantees a permanent growth process. Meristematic growth is characterized by the synthesis of proteins and nucleic acids and hence needs N. It thus seems that N is needed for the synthesis of essential macro-molecules. So, both play crucial role in meristematic growth (Koch and Mengel, 1977; Trolldenier, 1977). In this process phytohormones and $K^+$ are involved in a synergistic way. Sufficient stem growth is obtained only if gibberellic acid application was combined with a $K^+$ treatment (Dela Guardia and Benlloch, 1980) and the growth rate of cotyledons was only satisfactory if cytokinins were applied along with $K^+$ (Green, 1983).

Meristematic growth is characterized by the synthesis of proteins and nucleic acids and hence requires N. It thus appears that N is needed for the synthesis of essential macro-molecules, $K^+$ is required for balancing the ATPase activity and also for providing a high $K^+$ concentration in the cytoplasm attaining a levels of 100 to 120 mM and probably required for normal functioning of cytoplasmic processing (Glass and Siddiqi, 1984). It thus appears that $K^+$ and N play crucial roles in the process of meristematic growth. If the optimum growth rates of one are insufficient, the utilization of the other is impaired. The higher K supply enhanced the translocation of the nitrogenous compounds from roots and straws towards the grain (Herbert *et al.*, 2001). Uptake of N by roots may also be affected by K and vice versa. There is also evidence that nitrate nutrition helps in uptake of cations including K as compared with $NH_4$ nutrition (Mengel *et al.*, 1976; Kirkby, 1968; Ouyang *et al.*, 1998; Szczerba *et al.*, 2008). High N with low K favors lodging (Burkersoda, 1965). The N/K balance affects all aspects of quality in maize; protein contents, silage quality, 1000 grain weight (Burkersoda, 1965; Stangel, 1965; Trenholm *et al.*, 1998; Davidescu, 1965; Diuf, 1978; Haq, 1987).

**Potassium deficiency symptoms:** Symptoms of K deficiency are often hidden and less recognizable. The first sign of deficiency is reduction in growth rate. Plants become stunted and usually leaf color becomes dark green. At a more advanced stage, specific deficiency symptoms begin to appear. These include (a) decreased drought resistance (Mengel and Forster, 1973) and decreased excess water tolerance (Nelson, 1978), (b) appearance of white, yellow, or orange chlorotic spots or stripes on older leaves, usually starting from the leaf tips and margins. In some species irregularly distributed chlorotic spots appear, but in all cases symptoms start from the leaf tip (Bajwa and Rehman, 1996; Grundon *et al.*, 1997). The base of the leaf usually remains dark green, (c) the chlorotic area become necrotic, the tissue die and the leaves dry up, (d) the symptoms spread to younger leaves as K is mobile element and finally the entire plant may die (Tisdale *et al.*, 1990), (e) roots of K-deficient plants are poorly developed and often affected by rot, (f) disease incidence is increased and crop quality is severely reduced, (g) K deficient plants sometimes show increased incidence (Dobermann, 2001), (h) K deficiency symptoms are more frequent in no till or ridge till fields than with conventional tillage (Mallarino *et al.*, 1999), (I) dying old leaves show more K deficiency symptoms than the new emerging leaves (Bergmann, 1992), (j) K deficiency symptoms and yield response to applied K vary among corn cultivars (Dobermann, 2001), (k) incorporation of photosynthetic products into cellular components is inhibited or that the ability of the cotyledon to translocate photosynthetic products to the rest of the seedling is reduced in plants grown in K deficient conditions (Penny *et al.*, 1976).

Maize grown without tillage having K concentration in leaves equal to plants grown with conventional tillage when sampled at tasseling and substantially higher when sampled at the 8 to 10 leaf stage (Triplett *et al.*, 1969). Similarly beans with the same low K content showed only at high intensity the typical deficiency symptoms, namely chlorosis and necrosis, but not at low light intensity (Cakmak, 2003). Excessive reactive $O_2$ species propelled by high light intensity and at the same time, the reduced photosynthesis in response to inadequate K supply. K deficiency symptoms can also usually appear on younger leaves for instance in cotton on twigs with a high boll load because the high K demand of developing bolls have to be met from those leaves attached adjacent to the fruits (Pettigrew, 2008). Low crop quality and high susceptibility to biotic and abiotic stress are not attributed to inadequate K supply. Numerous field trails, also conducted by IPI, showed obviously that crop quality is improved when balanced fertilization with adequate K is applied. The higher resistance of plants to pests and diseases at adequate K supply is as well documented as the better appearance at soil borne and climatic stress situations like salinity, drought or frost (Marschner, 2005; Kafkafi, 1990).

When there is an abundant supply of K, plants can absorb K in excess of quantities required for normal functioning. This is called luxury consumption. In this case, the application of K fertilizer may not finalize in increased yield but may lead to depression in yield if the accompanying N and P are not sufficient (Bajwa and Rehman, 1996; Tisdale *et al.*, 1990). Splitting K application consistently increased available K in the soil over single applications. Luxury consumption of K can be reduced by making split applications of K at no more than half the N rates on soils kept low in available K (Burton and Jackson, 1962).

**Yield and its production attributes:** In literature, however, there is controversy over the application of K. Many authors (Chaudhry and Ahmad, 2000; Leon, 1999) reported the positive effect of K on maize growth, yield and quality parameters. The growth and yield components of maize like leaf area (Rasheed, 2002; Meille and Pellerin, 2008), crop growth rate (Cassman *et al.*, 1989; Ebelhar and Varsa, 2000; Heckman and Kamprath, 1992; Mullins *et al.*, 1994; Pettigrew and Meredith, 1997; Wyn Jones *et al.*, 1979), net assimilation rate (Mahmood *et al.*, 1999; Akhtar *et al.*, 1999), plant height at maturity (Asghar, 1999; Aslam,1994; Latif, 1989; Njeru, 1983; Obi, 1984), number of grain cob$^{-1}$ (Abid, 1989; Iqbal, 1998; Moslov and Chernova, 1976; Shah 1984; Shahzad, 1987), Cob length (Serpa *et al.*, 1984), 1000-grain weight (Rashid, 1994; Kolcar, 1975; Munson, 1968), grain and biological yield (Ali *et al.*, 2004; Albinet, 1978; Azink and Kajfez, 1983; Grewal *et al.*, 1982; Mallarino *et al.*, 1991; Pettigrew, 2008; Roy and Kumar, 1990) are significantly increased by K application. Correspondingly, quality parameters like crude protein contents in grains (Blevins, 1985; Diuf, 1978; Usherwood, 1985), crude starch contents in grains (Liang, 1985; Mahmood *et al.*, 2000; Burkart and Ambarger, 1977) and crude oil contents in grains (Ali *et al.*, 2004; Hanif, 1990) appreciably increased by K application.

Response of crops to K application have been extensively reviewed and evaluated by Bhatti (1978) and Saleem and Bertilsson (1978) in literature. In many cases, responses were not consistent and varied among crops and soils. Where responses were observed they were uneconomical (Saleem and Bertilsson, 1978). The average yields with the application of N+P could be further increased by 9 per cent with addition of K (NDFC, 1980). Experiments in Dera Ismail Khan and Swat districts and Malakand agency, Pakistan (Rehman, 1985; Bhatti *et al.*, 1983, 1985; Bakhsh *et al.*, 1986) showed responses of maize to application of K.

On the other hand, Parsad and Shrivastava (1992) and Rehm and Lamb (2004), differ to this doctrine that K application contributes to growth and development of the crops. Chaudhary and Malik (2000) claimed that K application in maize had non-significant effects on cob yield, grain protein contents, days taken to 50% silking (Ali, 1995; Cheema *et al.*, 1999), number of cobs per plant, number of plants per unit area and harvest index. Similar observations were noted by Sharif (1999) and Roy and Kumar (1990).

It should be clear that a properly managed $K^+$ fertility program is essential to achieve the maximum crop productivity. When soil and plant $K^+$ levels are not maintained at sufficient levels, economic losses can occur because of reduced production of grain and fiber or biomass (Bukhsh *et al.*, 2011c). Much of this yield loss can be attributed to the aforementioned reduced overall production of photosynthetic assimilates when K levels are insufficient (Subedi and Ma, 2008).

Supplemental $K^+$ fertilization is often required to achieve or to maintain maximal maize yields, particularly on soils testing low for native available soil $K^+$. Many researchers have reported maize yield increases in response to $K^+$ fertilization (Ebelhar and Varsa, 2000; Heckman and Kamprath, 1992; Mallarino *et al.*, 1999). However, Bruns and Ebelhar (2006) did not find $K^+$ fertilization to improve grain yield, although they reported increased $K^+$ tissue concentrations as a result of $K^+$ fertilization. A part of the maize yield enhancement from $K^+$ fertilization is because of a reduction in stover lodging with the $K^+$ fertilization, especially when higher N rates are used (Welch and Flannery, 1985).

Increased ear size with $K^+$ fertilization also contributed to the grain yield increases seen with $K^+$ fertilization. Whereas Heckman and Kamprath (1992) reported that $K^+$ fertilization increased the stover dry matter at maturity, Ebelhar *et al.* (1987) did not find that $K^+$ fertilization improved leaf weight or stover weight at silking. Increased stover weight in response to $K^+$ fertilization, if present, may help explain the reduced stover lodging observed with $K^+$ fertilization (Welch and Flannery, 1985). K fertilization can help lessen stover lodging in maize (Beaton and Sekhon, 1985). This yield improvement with K fertilization generally comes about because of increases in the grain weight (Haeder and Beringer, 1981; Sharma *et al.*, 2005; Sweeney *et al.*, 2000). Occasionally, an increase in the number of heads per unit area and the number of grains per head contributed to the yield increase (Haeder and Beringer, 1981), but in other studies, this trend was not observed (Sweeney *et al.*, 2000; Bukhsh *et al.*, 2011b).

**Potassium application improves crop quality:** When we talk about the revenue, an agricultural producer receives from the marketplace it is derived from two functions: (1) the amount of product delivered to the market and (2) the quality of the product delivered to the market. Although product quantity is the major function driving the producer's revenue stream, product quality can also determine some of this economic return. In fact, for some crops, quality plays an increasing role and in some cases the dominant role in generating revenue. K can play a role in quality development of many crops (Usherwood, 1985). When supplemental $K^+$ fertilization was applied to maize, it produced an increase in crude protein contents in grains and amino acid content (Usherwood, 1985). Supporting this high crude protein contents concept are the findings of Yang *et al.* (2004) that when maize was grown without manure in China, a greater crude protein contents in grains was produced using a balanced N-P-K fertilizer rather than using a fertilizer composed of only N and P.

$K^+$ influences the underlying physiological processes that determine crop yield and quality production and then traces how these impacted physiological processes alter the resulting yield and quality. With the ever increasing costs of the inputs involved in producing a crop, future research might well be directed toward determining ways that the plant can make more efficient use of the K available to it. An improvement in K-use efficiency would probably be best accomplished by first developing crop genotypes with larger or improved root systems to more efficiently remove K from the soil (Cassman, 1998). Of course, for this improvement in K uptake efficiency to effectively translate into more efficient use of the K or improved yields, other potential rate limiting steps must also be removed or mitigated (Bukhsh *et al.*, 2011b).

K is also involved directly or indirectly in plant protein metabolism (Blevins, 1985; Rehman *et al.*, 2008). This involvement can begin with the stimulation of $NO_3^-$ uptake and transport within the plant, as $K^+$ serves as the accompanying counter cation (Blevins *et al.*, 1978a, 1978b). In addition to this, Mengel (1980) also showed that the transport of amino acids is enhanced by higher $K^+$ levels, especially the transport of amino acids to developing seeds. K involvement is crucial for most in steps of the protein synthesis process, beginning with enzyme activation and continuing through ribosome synthesis and mRNA turnover (Blevins, 1985; Evans and Wildes, 1971). Although most of this research was performed using *Escherichia coli*, it is reasonable to predict that the findings would also be applicable to plants. Reinforcing the connection between $K^+$ levels and protein is the observation that crops with high seed protein concentrations also tend to have high $K^+$ harvest indices (Blevins, 1985).

**Epilogue:** The above review leads to the following generalizations/conclusions:

1. Maize is a particular cereal crop which is more affected by variations in plant density than other members of the grass family, due to its low tillering ability, its monoecious floral organization and the presence of a brief flowering period.
2. Different maize cultivars respond differently to K application under varying plant densities, due to different root/shoot ratio, growth rate, crowding stress tolerance, intra-specific competition between plants, K uptake and utilization.
3. Maize cultivars have the ability to withstand high plant density due to more partitioning of assilimilates to shoot as compare to root, resulting in reduction of root/shoot ratio. K application reduces the percent of senescent stalks, lodging and increased crushing strength and rind thickness.
4. There is general consensus that the soils of Pakistan have large capacity to provide K to crop under ordinary conditions, but the increase in the intensity of cropping, excessive use of the tube well water, introduction of the high yielding cultivars requiring high K, increasing use of N and P, could hasten the removal of K from the soils and imbalance the uptake of K in relation to other nutrients.
5. Genotypic and crop species differences exist in response to soil and fertilizer K and non-yield traits such as stalk strength or product quality must be taken into account in K management decisions.
6. K application not only increases grain yield, but also improves quality parameters.
7. K application improves utilization of water, tolerance to drought through stomatal conductance, acceleration in photosynthesis process, water up take through roots.
8. K application improves leaf area, dry matter accumulation and other allometric parameters.
9. K in combination with N has synergistic influence in uptake, translocation and utilization of nutrients for assimilation in growth and development of final grain yield and its contributing attributes.
10. Normally K deficiency symptoms are usually not conspicuous although grain yield is abruptly decreased (called hidden hunger), but severe deficiency do express symptoms.

**Conclusion:** Luxuriant application of K is inevitable for getting successful and maximum production from maize hybrids.

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