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Potassium in tea (*Camellia sinensis* (L) O. Kuntze) cultivation from soil to cup quality-A review

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ABSTRACT

Tea *(Camellia sinensis* (L) O. Kuntze) plants require comparatively higher quantity of potassium for production and quality of produce. After nitrogen, potassium is the second major nutrient for tea plant. Potassium plays vital role in enzyme activation, water relation, photosynthesis protein and starch synthesis. It offers abiotic as well as biotic stress toleration in tea plants and also improves biochemical parameters and organoleptic quality of tea. However, owing to the climatic conditions and soil mineralogical compositions, tea soils are predominantly poor in their potash content. Thus, the need based adequate supply of potash through inorganic or organic sources as soil application or foliar nutrition in tea growing soils of India is essential to realize the optimum economic yield with desired quality. Furthermore, the possibilities of development of potassium solubilizing biofertilizer with identification of native strains of microbes and development of potassium efficient tea genotype need to be explored. Such attempts minimize the cost of cultivation, sustain soil fertility and prevent environmental pollution.

Key words: Made tea quality, Potassium management, Stress resistance, Tea, Tea soil.

INTRODUCTION

Potassium (K) third important plant nutrient, (Meena *et al*., 2014) is also the second most important nutrient after nitrogen for tea (Ranganathan and Natesan, 1985). Tea plant is considered as a calcifuge, and does not grow well in soils of high base saturation (Eden, 1976). Tea rather requires comparatively higher quantity of K for better production and quality of the produce (Subba Rao and Brar, 2002). K plays vital role in enzyme activation, water relation, translocation, energy relations, translocation of assimilates, photosynthesis and protein and starch synthesis (Mengel and Kirkby, 1987).

Without adequate supply of K, the plants will have inadequately developed roots, hence will grow slowly with lesser yields (White and Karley, 2010) and increased susceptibility to diseases and pest (Troufflard *et al*., 2010). Application of K imparts drought tolerance of plants and improves quality of the produce (Jessy, 2010). The response of the yield of tea to added potassic fertilizer differs in relation to the sufficiency of K available in soil. The availability of K in most tea soils is not adequate due to the acidity and will reduce further as the soils become more acidic. Thus, the possibilities of responses to the applied K fertilizer will, therefore, increase as soil pH reduces (Willson, 1975 b). K deficiency emerges after a certain interval on soils where there was originally no response to applied K fertilizer (Ali *et al.,* 1977; Godziashvili and Peterburgsky, 1986). K deficiency has an apparent consequence on the recovery of pruned tea and on the bush frame health (Wilson, 1975b). Continuous cropping without K fertilization reduces economic yields and sometime causes death of the plants. K fertilization therefore becomes imperative and with the future passage of time application levels need to be extended (Ranganathan *et al*., 1988 and Malenga, 1986 b). In addition to above, recent climate models predict that incidences and duration of drought and heat stress periods are increasing in many regions, negatively affecting our major crops, - and thus our food security. Therefore, major challenges for agriculture are to improve crop yields in more resource effective systems and to sustain plant development, yield formation under biotic and abiotic stress conditions (Reynolds *et al*., 2011). The salient achievement of studies made so far on importance and role of K in tea culture is furnished in Table I.

K in tea soils: The major portion of K in tea soil is present in inorganic form bound to soil colloids (Anonymous, 2011). The threshold value of available K in soil could be between 150-200 ppm and even at that levels, 48-54 % could get depleted at the end of cropping season (Anonymous, 1983-84). In general, available K was higher in top soil than sub soil (Singh *et al*., 2011). A large number of agricultural soils including tea plantations are commonly low in plant available K (Bagyalakshmi *et al*., 2013). Tea naturally grows in tropical to temperate conditions, where the annual rainfall is more

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Table I: Major outcome of research on role of K in tea culture.

Salient achievement	Reference
K induce resistance in tea plants against *Helopeltis theivora*	Andrews (1923)
Total K in a tea soil varies between 0.15-1.0 %	Cooper (1924a)
K in most of the tea soils is not adequate due to the acidity	Willson (1975 b)
Threshold value of available K in tea soil could be 150-200 ppm	Anonymous (1983-84)
K improved leaf water potential and water use efficiency of tea plants	Saikia and Dey (1984)
Foliar nutrition of K acts as osmoticum and assists to sustain water potential of the tea plant	Handique and Manivel (1990)
K promotes amino acid and polyphenol contents in the shoots which enhance quality parameters of black tea	Ruan *et al.* (1998)
The first stage of K deficiency causes gradual reduction in yield	Verma (1999)
K stimulate more build-up of organic solute, proline in tea leaf at the time of abiotic stresses	Barman *et al.* (2005)
Soil reserve K and their release pattern are important for nutrition point of view	Venkatesan and Senthurpandian (2006)
K improved important liquor components of black tea such as TF, TR and its ratio	Venkatesan *et al.* (2006)
K status in tea soil depleted immediately after conversion to organic	Baruah *et al.* (2011)
Tea Rhizospheric K-solubilizing strains increased solubility of mineral K	Bagyalakshmi *et al.* (2013)
Combinations of thiamethoxam + MOP/SOP and bifenthrin + MOP/SOP improved the control of *Helopeltis theivora*	Rahman *et al.* (2014)
The P × K interaction was found positive to maintain the linear response to nitrogen	Verma and Pund (2014)

than 200 cm (Hadfield, 1968). Soils of the high rainfall region have been highly leached and generally have low K content (Havlin *et al*., 2003). Tea soils are highly weathered and have kaolinite clay minerals, where there is hardly any binding site for K, which necessitated frequent application of K fertilizers (Venkatesan and Murugesan, 2006). Acid soils of Assam fix K partly by physical adsorption and chemical interchange of bases (Carpenter and Harler, 1921b). In spite of the diversity of soil, the tea growing soils are acidic and found under or exist in high rainfall conditions. Since the predominant clay mineral is kaolinite, these soils are low in cation exchange capacity (CEC) and bases. The soils dominated by kaolinite clay minerals, have no inter lattice binding sites for K, and hence cannot hold any non-exchangeable K (Patil *et al*., 1976). Darjeeling tea soils are classified as sedimentary type (Verma, 1997) and are sandy loam in texture (Rai and Mukhopadhyay, 2012). Most of the tea soils of Darjeeling hills (about 86 %) are low to medium in available K content (Saha, 2004). Crops grown on coarse textured alluvial soils and some shallow black soils need K fertilizer for optimum crop production (Subba Rao and Rao, 1996). Additionally, in intensive agricultural production systems, K has become a limiting nutrient, in particular in sandy or organic soils (Goulding and Loveland, 1986).

Soils inherently low in K are often sandy, waterlogged, saline, or acidic (Zorb *et al*., 2014). The availability of K to the plants depends directly on the concentration of K in soil solution and indirectly on soil (Goldstein, 1994).

K in soil is classified into four groups depending on its availability to the plants: water-soluble, exchangeable, non-exchangeable and structural form. Water soluble K is directly available for plants and microbial population and also exposed to leaching losses (Barre *et al*., 2001). Non-exchangeable and structural forms are considered to be slowly or non-available K sources for plants. However, these pools may also contribute significantly to the plant supply in the long term (Pal *et al*., 2001). Lattice K had a beneficial and important correlation with the other forms of K *viz.* non-exchangeable and total K. The poor relationship with soil properties is due to the inertness of lattice K (Basumatry and Bordoloi, 1992). Apart from fertilizer, non-exchangeable K is the major source of K requirement of tea and therefore, characterization of soil reserve K and their release pattern are important as far as nutrition is concerned (Venkatesan and Senthurpandian, 2006).

K in relation to tea yield and quality: Available K content of the top soil is found to be linearly correlated with yield at a productivity level of 82 % (Anonymous, 1982-83). Foliar application of muriate of potash (MOP) improves the root starch build-up and escalates the crop yield in tea (Barman *et al*., 2003). K deficiency causes critical depletion in photosynthetic CO_2 fixation and reduces the partitioning and assimilation of photosynthates (Cakmak, 2005). K has been described as the 'quality element', ensuring optimum quality of agricultural produce (Imas, 2013) and reported to show positive impact on the quality of made tea (Ranganathan and Natesan, 1985). Therefore, balanced fertilizer application including K is important for getting high quality products.

The nutritional quality of plant products is a highly complex trait composed of appearance, nutritional, sensory, shelf life and technological quality (Zorb *et al*., 2014). However, colour, brightness, strength, flavour and briskness are the major parameters which regulate the value of marketable tea (Venkatesan *et al*., 2006). Darjeeling tea is known worldwide for its muscatel aroma and flavour. Quality of Darjeeling teas is embedded in its unique flavour and is characterized by 'Darjeeling tea character'. Since, teas are

valued for their aroma, having direct relationship with flavour index (Owuor, 1992) and application of huge amount of N fertilizer without balancing with K may be detrimental to the tea quality. The type of tea cultivar/clone, farming system, prevailing climatic conditions and geographic location etc. also substantially influences the quality of made tea. However, the favourable effect occurrence due to fine tuning of the nutritional aspects cannot be ignored as it is also one of the major component to govern the soil fertility status (Ruan *et al.,* 1998). Several studies have been carried out to study the effect of soil fertility management practices on the quality of various types of tea (Rahman *et al.,* 1978). Use of high amount of nitrogen fertilizer lower the flavour index and theaflavin (TF) content while improving the caffeine content (Owuor and Odhiambo, 1994). TF and thearubigins (TR), the significant quality parameters of black tea, were shown to be enhanced with improved K application in Chinese cultivation practices (Ruan *et al.,* 1998). The ideal N: K ratios for highest production and biochemical properties was found to be 1:0.83 or 1:0.62 if the source of K was MOP, while it was 1:0.21 or 1:0.42 for sulphate of potash (SOP) in south Indian conditions (Venkatesan *et al.,* 2006). Hence, any modification in fertilisation practice is supposed to have an effect on the quality of made tea, depending on the overall farming practices. Since majority of tea growing areas belong to either highly responsive or in responsive categories towards externally applied K, the frequency of fertilizer application shall be increased to enhance the agronomic efficiency.

Tea yield and quality in relation to K sources: Researchers from China reported that addition of MOP can have detrimental effect on biochemical properties (Wu Xun, 1995); although experiments in south India showed a linear improvement in the biochemical properties against rate of K application, and relatively small quantity was found sufficient to increase the same parameter in the case of SOP (Venkatesan *et al.,* 2005). Neither of the two sources affected the chlorophyll content of tea shoots, regardless of their level over control. K supplied as MOP increased the liquor characteristics such as TF, TR and TF/TR ratio at higher levels. Similar result was recorded at lower level itself when the source of K was changed to SOP. Termination of K application decreased the TF/TR ratio sharply (Venkatesan *et al.,* 2006). The polyphenols and its oxidized derivatives (especially TF and TR) are major chemical constituents, which are liable for brightness and colour development of tea during infusion action and the distinctive aroma of black tea (Venkatesan and Ganpathy, 2004). The direct increase of polyphenols with the application of K fertilisers has been documented (Ruan *et al.,* 1999). A detrimental effect of manuring on overall quality and biochemical properties was noticed when huge quantity of N or K was individually applied. However, it is quite clear from the observations that a major increase in quality could be achieved when a balanced N K ratio (1:0.83) is used for fertilizer application in the field (Venkatesan and Ganpathy, 2004). An improvement in polyphenol and amino acid contents has been noticed with increasing level of K application. A beneficial and significant correlation has been found between nitrate reductase activity and the amino acid content of the pluckable tea shoots (Venkatesan *et al.,* 2004). Enhanced levels of N and K fertilizers escalate the chlorophyll contents of leaves which could increase the blackness of tea liquor (Krishnapillai and Ediriweera, 1986).

K in relation to tea stress resistant: Foliar nutrition of K acts as osmoticum and assists to sustain water potential of the tea plant (Handique and Manivel, 1990). In literatures, high K content in crops has usually been termed "luxury consumption." However, this high K accumulation by crops may be considered as an "insurance strategy" to empower the plants to withstand under a sudden environmental stress (Kafkafi, 1990). MOP application stimulate more build-up of organic solute; proline in tea leaf which is an adaption mechanism of moisture at cellular level at the time of abiotic stresses (Barman *et al.,* 2005) and attempt to minimize the impact of drought. It has been established that a more amount of applied K and shot hole control measures in the pruned year help to build up the health of tea bushes by improving the hardiness of stem tissues and protecting them from new attack in early stages of growth (Ranganathan and Natesan, 1985). Higher dose of K (N: K_2O at 1:2) in the pruning year to protect tea bushes from fresh attack of shot hole borer has been recommended for south Indian tea (Verma, 1997). During drought condition, soil application of K_2O @ 168 kg ha^{-1} improved the leaf water potential and water use efficiency of tea plants (Saikia and Dey, 1984). Foliar application of aqueous solution of MOP combined with urea, each at 1% under south Indian conditions contribute drought tolerance to the mature tea bushes when supplied four times at monthly interval from the month of November/ December onwards (Verma, 1997; Kumar and Kumar, 2010). Similarly, in a study conducted at Tocklai it is reported that foliar application of MOP @ 2% at 21 days interval during moisture deficit period of soil (December-March) increased photosynthesis, water use efficiency, root starch accumulation and cuticular waxes which restrict transpiration loss and also increased proline which protect the cellular damage due to drought (Barman *et al.,* 2011). K application at higher doses, suppressed significantly the population of the root- lesion nematode, *Pratylenchus loosi* (Gnanapragasam, 1982). The effectiveness of applying higher amount of K in the pruned year for control of shot-hole borer is being established (Muraleedharan, 1985). Potassium acetate addition to the fertilizer mixture enhanced the saponin activity of the tea stem induced in a marked decrease in the population of *E. fornicates* larvae (Wickremasinghe and Thirugnanasuntharan, 1980). In a recent study Rahman *et al.,* (2014) reported that the control

of *Helopeltis theivora* achieved by the combinations of *thiamethoxam* + 2% MOP/ SOP and bifenthrin + 2% MOP/ SOP was found to be statistically significant compared with the sole application of the insecticides. Earlier studies have also reported that K could induce resistance in tea plants against *Helopeltis theivora* (Andrews, 1923 and Aggarwal, 1985).

K RECOMMENDATION

K recommendation for North East (NE) Indian tea soil: Response of applied K has been observed in the nursery, young and mature tea plants. K play crucial role in the development of robust bush frames, which is necessary to sustain productivity of tea for longer period. The need for K fertilizer application was established in the early 1970s (Dey, 1971), which were subsequently supported by biochemical investigations (Dev Choudhury *et al.,* 1983). Amount of total K in a tea soil varies between 0.15-1.0 %. It was generally found that in sandy soil, when this quantity approached a lower figure, K manuring show large direct increase in crop yield. The bigger the crop, the more rapid was the depletion of available K in soil (Cooper, 1924a). Since widening in yield difference over a period of time between fertilized and unfertilized tea was observed it was thus suggested to improve K application levels after certain period in young clonal tea (Rahman and Jain, 1985). Application of K_2O elicited remarkable responses and tea yields increased in all the six 3- year cycles (Fig. 1). Further, findings of NPK experiment in NE India on mature tea revealed that for sustaining yield upto 2300 kg ha^{-1}, the required K was 80-140 kg K_2O ha^{-1} which improved to 160 kg K_2O ha^{-1}, when the yields were elevated to 3500 kg ha^{-1} or more along with needed N and P (Biswas and Chakravartee, 1992). The tea yield of 2000 kg of made tea ha^{-1} $year^{-1}$ remove N, P_2O_5 and K_2O at 100, 20 and 40 kg ha^{-1}, respectively. If the pruning litter is not retained in the field, additional loss of N, P_2O_5 and K_2O at 100, 20 and 40 kg ha^{-1} took place, respectively (Singh and Mishra, 2009). N dose increases from 20-40 kg ha^{-1} in first year to 140-145 kg ha^{-1} in fifth year of planting. On the ground of average productivity (pruning cycle productivity) and the soil K status, N, P_2O_5 and K_2O should be supplied in the ratio of 2:1:2 or 2:1:3 in mature tea in NE India. The dose of K_2O varied from 90-165 kg ha^{-1} in mature teas for plain district of NE India based on productivity and soil K_2O level. 90 kg K_2O ha^{-1} is applied when average pruning cycle productivity is upto 1500 kg made tea per hectare (KMTH) and 165 kg K_2O is recommended when yield is 2500-3000 KMTH and soil K_2O level is below 60 ppm (Singh and Mishra, 2009).

K recommendation for South Indian tea soil: Appropriate application of K is necessary for sustaining growth and yield of crops. Plants do not show any visible traits until K become highly deficient. With the improvement in productivity and reduction of available soil K, deficiency of K start to exhibit in tea growing regions of south India in the mid-sixties. Reduction of roots starch reserve, degeneration of feeder roots and accumulation of nitrate causing decline in bush

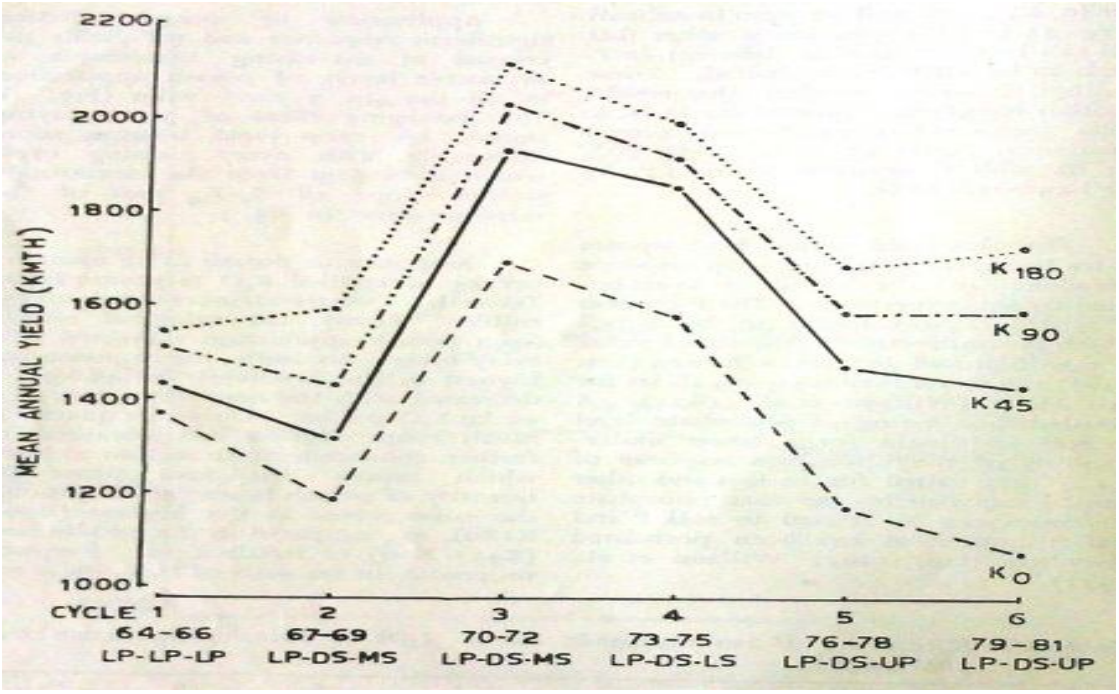


Fig 1: Response of young clonal tea to K_2O fertilizer application over six pruning cycles. Source: Rahman and Jain (1985). Reproduced by permission of the Secretary, Indian Society for Plantation Crops.

health and die back was noticed when K application was not matched with N. On a K deficient soil, there will be a slow decrease in growth rate and yield accompanied by tip and margin scorch of mature tea leaves. It is followed by early leaf drop leaving a crown of young foliage at the top and generation of thin frame wood (Troufflard *et al*., 2010). The first stage of K deficiency causes gradual reduction in yield (Verma, 1999). Decline in new flush growth and poor recovery after pruning and ultimate death of the plants are also reported. Visual symptoms of K deficiency on tea plants was observed six years after withholding K application but yield decrease was noticed in the very first year. The yield reduction was 17% in the first year and became 32% in the 13th year of withholding K application compared to the plots receiving 40 kg K_2O ha^{-1} (Ranganathan, 1970a). Tea plant after its two formative pruning is known as mature tea. Results in south Indian condition on the response of mature tea to K_2O have shown up to 250 kg ha^{-1} year^{-1} (Ranganathan and Natesan, 1985). The release of K from the soil source is inadequate in relation to plant needs; K is best applied in as many doses as possible in relation to crop requirements and the most practical way is to apply the same with every nitrogen application (Ranganathan and Narayanan, 1974). Pruning is an important cultural activity in tea cultivation. Tea in the pruned year mobilizes high amount of nutrients within a short period for the formation of robust and healthy bush frames and adequate foliage to start the cycle for yield generation (Natesan *et al*., 1984b). The N-K interaction in tea is well established. It is well known that lack of K limits the yield response to N. When N: K_2O ratio is adequate, the assimilation of K_2O in relation to N is highest in the roots followed by twig, wood, flush shoot and foliage. Thus, the requirement of K_2O in relation to N is important for young tea plants and in pruned year. The optimum N-K_2O ratios for tea in southern India, based on the interaction effects are 1:0.83 for nursery plants, 1:0.83 to 1:1.25 (based on soil pH and K availability) for young tea, 1:1.25 to 1:1.66 (depending on the type of prune) for mature tea in the pruned year following pruning and 1:0.45 to 1:0.83 (depending on the source of N and yield level) for mature tea other than in the pruned year (Ranganathan, 1982 and Ranganathan and natesan, 1983).

K management in tea soil: K requirement increases in the plant where soils lack adequate plant available K for crop production (Rengel and Damon, 2008). It is oftenly applied to the crop as K fertilizers in intensive as well as extensive agricultural systems (Zhang *et al.,* 2013). Fertilizer application is required to secure sufficient supply of available K to the crops. Monitoring of soil K reserves is, therefore, extremely important in order to make precise fertilizer recommendations. Soil extraction by neutral normal ammonium acetate method for determining exchangeable K is extensively used to estimate the K fertilizer demand of a crop. MOP, a naturally occurring mineral mined from deep deposits, is the important form of K fertilizer that is used nowadays. SOP and potassium nitrate, both side products from MOP mining, are also commercially available but are more expensive. Furthermore, organic manures viz. compost manures, slurry, biogas residues, or food waste etc. is also an important source of fertilizer K in agriculture. Application of both cattle manure and mineral fertilizer mixture (NPK) resulted in an increase in available K content of soil. K in organic wastes occurs predominantly as soluble inorganic K (Singh *et al.,* 2014). In a long term experiments at Tocklai it was observed that two splits application of K fertilizer above 100 kg K_2O ha^{-1} was superior to single application (Anonymous, 1985-86). In first split, 60% of the dose of K_2O should be applied in March-April and the remaining 40% should be applied in August-September as second split. In light-textured soils that have very limited capacity to retain K from leaching it may be more efficient to make two or three split applications, as these soils are also low in plant available K (Annadurai *et al.,* 2000). This practice may also be applied on soils that tend to fix K in order to increase K uptake (Zorb *et al.,* 2014). Weathering of K bearing feldspars and micas inherited from soil parent materials produces secondary soil minerals which represent the potential sources of plant-available K in soils (Singh and Goulding, 1997). Recent investigation suggested that addition of K containing primary mineral material waste mica may increase the long-term fertility of the soil by increasing the K depots (Basak and Biswas, 2009).

Microbes in relation to K management: Rhizospheric microorganisms are known to play major role in nutrient supply to the plant. K-solubilizing bacteria are known to release K from insoluble minerals by discharging organic acids (Sheng *et al*., 2002) and these bacteria are widely used in biological K-fertilizers and biological leaching (Lian *et al*., 2002 and Bosecker, 1997). Therefore, inoculation of K-solubilizing microorganisms in conjunction with application of rock-K to soil has recently gained a great deal of attention. The K-solubilizing strains isolated from rhizosphere of tea and used as biofertilizers of K in tea increased solubilizing capacity of MOP in comparison to mineral K sources (Bagyalakshmi *et al*., 2013). Application of K-solubilizing bacteria as biofertilizers can minimize the use of agrochemicals and support eco-friendly crop production (Archana *et al.,* 2012). The ability of K to be reused is unmatched by any other nutrients. Development of K efficient tea cultivars, especially in terms of the nutrient efficiency or quality of harvest products could open a new era for K management. In future perspective, use of K efficient cultivar in combination with optimized soil fertilization would be the best nutrient management policy for stable and sustainable farming systems (Rengel and Damon, 2008).

CONCLUSION

The review paper summarizes considerable up-to-date knowledge concerning the importance of K in tea plant growth, quality in changing climate, and details controlling K availability and dynamics in the soil. Imbalanced or excess use of chemical fertilizers imposes the negative impact on environment and also increasing costs of crop production. In view of current review, following points considered as thrust areas for future research to optimize/economize the K nutrition of tea soil and plants.

· Region and site specific time and method of K fertilizer application need to be readjusted for better utilization of applied as well as native K.

· Utilization of plant unavailable pool of soil K by the use of potassium solubilizing microbes (KSMs) which can also decrease the fertilizer requirement. The utilization of KSMs is considered to be a sound strategy in improving the productivity of agricultural lands. This new technique is also claimed to have the ability to restore the productivity of degraded, marginally productive and unproductive agricultural soils (Rajawat *et al.,* 2012; Basak and Biswas, 2012).

. Design and development of the more K-efficient tea genotypes by conventional breeding or targeted biotechnological strategies. Optimized K fertilizer supply in K limited soils are important in order to increase plant response especially to drought stress via improving adaptive/ resistance mechanisms of crop plants.

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