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Potassium nutrition in rice: A review

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ABSTRACT

Potassium (K) is the most neglected nutrient in Indian agriculture and accounts only 10% of the total fertilizer use. The increased cropping intensity and use of high yielding cultivars since the green revolution led to heavy withdrawal of K from soil. Persistent K mining over the past six decades has mined soil K level in many cultivated areas and continuously transforming sufficiency into deficiency. A recent soil test a little over 1 lakh samples from 33 states of India have categorized 41.1%, 29.3%, and 29.5% of soil samples as low, medium and high in available K respectively. Further, the trend of soil available K status showed a persistent decline in percentage of area under high and medium soil K. Consequently, the evidence of rice crop responding to K nutrition is increased. This review attempts the nexus of K nutrition in rice for devising strategies for potassium management in rice-based cropping systems in the country.

Key words: *Potassium, rice, yield, economics, split application*

INTRODUCTION

Potassium (K) is the most abundant cation in plants which provides tolerance to various biotic and abiotic stresses such as high/low temperature, disease, insect pest and drought. Besides, K helps in photosynthesis, osmo-regulation, enzyme activation, protein synthesis, ion homoeostasis, and stability between monovalent and divalent cations (Kanai et al., 2007; Amtmann et al., 2008). Research reports indicate that K activates at least 60 enzymes in the plant metabolism and thus influences growth, development, yield and quality (Sekhon, 1999).

Notwithstanding to these revelations, K has long been a neglected nutrient in Indian agriculture. K shares only one-tenth of the total NPK consumption since the past 5 decades (Tiwari, 2003). K consumption has increased from 0.5 kg ha^{-1} in 1965-66 to about 12 kg ha^{-1} in 2015-16, which is just 9% of the total NPK consumption per hectare in 2015-16. K is required in large quantities for growing crops, but farmers often do not fertilize their crops with sufficient K due to high costs, which led to depletion of available soil K reserves in large areas of farmland across the world (Srinivasarao et al., 2014). In recent years, K became a limiting element in intensive agricultural production systems, where insufficient K fertiliser application was more prominent. In contrast to nitrogen (N) and phosphorus (P), K fertilisers are applied at a much lower rate, and less than 50% of the K removed by crops is replenished through application of various manures and fertilisers (Sardans and Penuelas, 2015).

Application of K to rice is still debated in forums. Two types of argument are going on *viz*., Indian soils are rich in K and may not require external application of K and secondly the presence of K-bearing minerals in the soils does not necessarily mean that crops have access to the required K nutrition. The demand for external K fertilizer input is increased sharply over the years due to practicing of intensified multiple cropping system with modern high yielding varieties. Besides, whether or not we replenish K through fertiliser or other sources (organic matter, crop residues, irrigation water, etc.), plants are going to extract K from the soil to produce certain yield. In the absence of external supply, plants will fulfill their requirement from the native reserve K present in the soil, leading to depletion of soil K reserve, which is largely ignored and undetected by the conventional soil tests for K.

Trend in K status in Indian soils in the post green revolution era

The available K status of Indian soil was periodically analysed and reported in the literature since 1960 (Tamhane and Subbiah (1960), Ramamoorthy and Bajaj (1969), Ghosh and Hassan (1976), Motsara and Singh (1981), Motsara (2002), Hasan (2002) and Muralidharudu et al. (2011) (Table 1). As early in 1960, Tamhane and Subbiah (1960) reported that 63.7% of the representative soil samples across the states were low and medium in available soil K while the remaining were high in available K. Three years later, Ramamoorthy and Bajaj (1969) found that 20%, 53% and 27% of 184 sample districts fell in low, medium and high K categories, respectively. Hasan (2002) reported a similar trend from another 371 districts. Altogether, 72% of India's agricultural area, representing 266 districts, demand K fertilisation. A decade later, Muralidharudu et al. (2011) have estimated more districts under high available K category covering 500 districts [47 (9%) low, 212 (42%) medium and 239 districts (49%) were high in available K]. A zone wise comparison exhibited a different picture apparently due to change in cropping systems *viz*., 54, 23, 59 and 32% districts in north, west, east and south zone, respectively were classified as medium in available K. K deficiency was most wide-spread in east zone (59%) followed by north zone (54%). Since K fertilisers were seldom applied in the last two decades the soils under 'high" category further reduced (Pathak, 2010). Yadav and Sidhu (2016) were of the opinion that 72% of agricultural soils in India require immediate K fertilization or balanced fertiliser application to maintain sustainable soil health as well as the productivity. The recent soil test value, based on analysis of 101992 samples from 33 states of India showed 41.1%, 29.3% and 29.5% of samples were low, medium and high in available K (Table 1).

These assessments showing soils of over 50% districts in India in the low and medium K fertility category, do not support the generalized notion that all

Table 1. Trend in K status in Indian soil from post green revolution era.

Number of soil samples	Number of districts studied	Percent of the districts sampled			Reference
		Low	Medium	High	
1.3 million	184	20	53	27	Ramamoorthy and Bajaj (1969)
4.5 million	310	20	42	38	Ghosh and Hasan (1976)
-	361	13	53	34	Anonymous (1988)
3.65 million	-	13	37	50	Motsara (2002)
	371	21	51	28	Hasan (2002)
	500	9	42	49	Muralidharudu et al. (2011)
101992	33 state	41.1	29.3	29.5	Authors collected from Indiastat.com

Source: Modified from Dey et al. (2017)

Indian soils are rich in K. Two major reasons for growing K deficiency in India's soils are; lower rate of K application against normal recommended rate and higher removal of K from the soil compared to addition through intensive cropping. It was suggested that no application of K in low and medium K fertility soils restrict farmers from achieving maximum yields and they respond to K fertiliser application (Singh et al., 2014).

Potassium fertilizer use in India

In India, fertiliser prices are the chief determinants of farmers' fertilizer practices, rather than the science of crop requirement or balanced fertilization besides the fertiliser subsidy. In 1992-93, the K consumption was reduced by 0.5 million tonne (Mt) from the previous year's consumption (Chander, 2017) apparently due to an increase in K_2O price. Temporal K consumption data over the last six decades clearly showed a fairly consistent linear increase of K consumption up to 2010 and a decline thereafter. The nutrient-based subsidy scheme in April 2010, made K fertilizers dearer through a reduction in the subsidy on K fertilizer, with a consequent reduction in the K consumption by 1.0 Mt over the preceding year pushing the skewed nutrient ratios (FAI, 2016). The nutrient consumption ratio of N: P: K is shifted from 4.7:2.3:1.0 in 2010-11 to 6.4:2.5:1.0 in 2018-19. Thus, mining of soil K was certain (Table 2). The per hectare application of N, P and K fertilizers data shows that the N application increased from 1.4 to 89.1 kg/ha from 1960 to 2015 whereas K consumption increased from 0.2 to 12.3 kg/ha during the same period (Table 2).

Problems associated with imbalanced K fertilization

Imbalanced K fertilization often leads to low nutrient use efficiency, soil and water pollution, luxury consumption, increased production cost since K is one among the three main pillars of balanced fertilizer use. The luxury consumption of K also pushes back the potassium use efficiency (KUE). In India, the evidence of luxury consumption of K in rice is very meagre and negligible. Although K application rate is very less due to non-scientific method of K fertilization causes luxury consumption K. It should be kept in mind that it is mandatory to replenish the nutrients to maintain the soil fertility under intensive cropping to balance nutrient mining. Such deficits on a continued basis causes decline in soil fertility and invite further imbalances in crop nutrition (Patra et al., 2016 and 2017). For example, during germination and seedling stage the demand for K is less as compared to peak vegetative growth stage and flowering. Basal application of entire recommended dose of K at the time of sowing leads to fixation of major portion of applied K in heavy textured soil and in light textured soil it is lost mainly through leaching.

Response of rice to potassium application

The response of rice crop to the externally applied K is a function of time, sources and method of K application and interaction of K with other nutrients (Bijay-Singh, 2004; Vijayakumar et al., 2019d; Vijayakumar et al., 2019e). Due to the availability and high K content, Muriate of potash (KCl) is a widely used source of K fertilizer for rice up to 99% of the total K fertilizer usage in the Indo-Gangetic plains although potassium sulphate

Table 2. Fertilizer consumption in India.

Year	Fertilizer consumption (000 t)			Fertilizer consumption (kg/ha)			Ratio of N: P: K
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	
1960-61	210	53	29	1.39	0.35	0.19	7.3:1.8:1.0
1970-71	1487	462	228	8.92	3.26	1.43	6.3:2.2:1.0
1980-81	3678	1214	624	21.3	7.00	3.60	5.9:1.9:1.0
1990-91	7997	3222	1360	43.1	17.3	7.20	6.0:2.4:1.0
2000-01	10920	4215	1567	58.9	22.8	8.50	7.0:2.7:1.0
2010-11	16558	8050	3514	84.9	41.3	18.0	4.7:2.3:1.0
2015-16	17372	6979	2401	89.1	35.8	12.3	7.5:3.0:1.0
2018-19	17628	6968	2779	89.7	35.5	14.1	6.4:2.5:1.0

Source: Department of Agriculture and Cooperation (DAC)

(K_2SO_4) is equally effective (Tandon and Sekhon, 1988). K_2SO_4 is recommended for salt affected and sulphur deficient soils (Zia et al., 2000).

Effect on growth attributes

Depending on the soil available K, rice has responded up to 125 kg K ha^{-1} in India with an increase in plant height, dry matter production, over its half dose in rice (Meena et al., 2003) even for hybrid rice (Das and Panda, 2004). Mukherjee and Sen (2005) reported increased plant height, LAI, chlorophyll content, number of tillers hill^{-1}, and dry matter accumulation of rice with the application of K (40 kg ha^{-1}) and rice husk (9 t ha^{-1}). Split application of K i.e 1/2 at transplanting and the rest at shooting stage increased plant height and dry matter (Bahmaniar et al., 2007) over basal application of entire dose of K (Vijayakumar et al., 2019c). In Tamil Nadu, application of 50 kg K_2O ha^{-1} in both *kharif* and *rabi* seasons promoted plant growth (LAI, dry matter production) and chlorophyll content (Muthukumararaja et al., 2009).

Effect on yield attributes

All the yield attributes of rice are influenced by K application. Based on on-farm multi location trials in six districts of Pakistan, Awan et al. (2007) found that the split application of recommended dose of potash (62.5 kg ha^{-1}) as 1/2 at basal and remaining 1/2 at 25 DAT (days after transplanting) increased yield components of rice *viz.*, maximum number of tillers per hill (27), grains per panicle (69), 1000-grains weight (22 g) and minimum percentage of the sterile grain (6.39%). Increasing levels of K up to 36 kg K ha^{-1} enhanced the number of effective tillers per plant (Alam et al., 2009) and up to 171 kg K_2O ha^{-1} in clay soil of Egypt (Abdel et al., 2004). Bahmaniar et al. (2007) found that application of K at two growth stages (1/2 at transplanting and 1/2 at shooting stage) increased number of tillers, length of the panicle, number of grains panicle^{-1} and reduced the percentage of sterile grain. In Tamil Nadu, application of 75 kg K/ha gave the maximum number of panicles hill^{-1} (9.06), panicle length (19.6 cm), 1000-grain weight (20.5 g) (Arivazhagan and Ravichandran, 2005). The application of 100% recommended dose of K in two equal splits *viz.*, half at basal and remaining half at panicle initiation stage produced maximum panicle length (28.6 cm), panicle weight (2.76 g), number of grains/panicle (111.9), filled grains/panicle (103.7) and fertility percentage (94.8%) (Vijayakumar et al., 2019c). Similarly, two foliar sprays of 2.5% potassium nitrate (1st at active tillering and 2nd at panicle initiation) increased fertility percentage (83.5%) of rice grain by 6% over control (Vijayakumar et al., 2019c). Insufficient supply of K during active tillering and panicle initiation stage, increased the production of unfertile tillers m^{-2} (Vijayakumar et al., 2019a). Bhushan et al. (2007) and Saharawat et al. (2010) found spikelet sterility is one of the causes of yield penalty in DSR and K fertilization (60 kg K_2O ha^{-1}) in DSR increased spikelet fertility (percentage of filled grains) (Mitra et al., 2001). In Assam, pre-sowing seed hardening with 4% muriate of potash (MOP) along with soil application of 40 kg K_2O ha^{-1} in direct sown summer rice (cv. Banglami), produced the highest number of productive tillers m^{-2} and filled grains panicle^{-1} (Kalita et al., 2002).

Effect of K on rice root parameters

Root architecture and its distribution pattern in the soil found an important mechanism to exquisite nutrients and water (Lynch et al., 2007; Yang et al., 2005) and K fertilization influence root architecture especially in dryland conditions. Moreover, the uptake of water and minerals are directly affected by root morphological characteristics (Marschner, 1995). The rice roots showed a distinct change with respect to K availability and its mobility in the rhizosphere (Yang et al., 2005) since K deficiency affects the root architecture (Jia et al., 2008). Root hair length is modified in response to the availability of K to crop and thereby it maintains the uptake from sparingly soluble K sources (Sustr et al., 2019). In rice, 70 and 90% of the root biomass was observed in the first 20 cm and 40 cm of the soil respectively, however the soil chemical property *viz.*, pH, EC, available N, P, K, and micro nutrients altered these characteristics (Fageria and Moreira, 2011). Root growth directly affects the growth of plant and above ground biomass. The K deficiency significantly reduced the root count per plant in both K-inefficient (Tonglianghuozhong, Jia948 and Xiangwanxian3) and K-efficient (HA-881043, Sanyangai and Xinzaozhan) genotypes. Filho et al. (2017) observed linear response between root length and shoot K concentration.

Effect of K application on rice yield

Using time series analyses, Bhargava et al. (1985) disclosed that, the response to K fertilization has been increasing with time since response to applied K is a function of crop, variety, soil characteristics and application of other nutrients. The response of rice to K in different agro ecological regions has shown a sharp increase from 1.8-8.0 kg grain kg^{-1} K during 1969-1971 to 6.5-10.7 kg in 1977-1982 underpins the need for its application in intensive rice-wheat cropping systems. Results of on-farm trial in rice showed a grain yield advantage of 240 kg ha^{-1} with 50 kg K ha^{-1} (Randhawa and Tandon, 1982) and a yield advantage of 1.3 t/ha in Punjab and Pakistan (NFDC, 2001) however, yield declined thereafter in rice-wheat system (Yadvinder-Singh et al., 2002). A dose of 25 kg K ha^{-1} resulted in increased rice yield by 280 kg grain ha^{-1} in a sandy loam soil (Meelu et al., 1995) while in a salt affected soils gave an additional yield of 0.50 t ha^{-1} of rice (Tiwari et al., 1998). Potassium fertilization in rice increased the grain yield by 12% in Pantnagar (Dobermann et al., 1995). Sahu (2001) pointed out that application of 132 kg K ha^{-1} increased average grain yield by 136% in cv. Jaya, 71% in cv. Pathara, 59% in cv. Mahsuri, and 42% in cv. Parijat based on three cropping cycle. Mitra et al. (2001) found a significant rise in rice yield with increasing levels of K (60 kg K_2O ha^{-1}) in north-western India (Gurdaspur and Ludhiana) after 6-years of experimentation. In Tamil Nadu application of 50 kg K_2O ha^{-1} increased grain (5263 and 5621 kg ha^{-1}) and straw (8445 and 9077 kg ha^{-1}) yield of rice in both *kharif* and *rabi* seasons primarily due to a significant decrease in chaff grains, increased number of productive tillers (Muthukumararaja et al., 2009). In Indo-Gangetic Plains (IGP) basal application of 60 kg K_2O ha^{-1} showed a yield advantage of 920 kg/ha over no K application (Vijayakumar et al., 2019c).

Effect of split application of K on rice yield

Time of application of K is very important in order to realize maximum benefit from K application (Table 3). Split application of K is more useful in light texture soil like sandy loam and silty loam since it reduces the leaching loss of applied K fertilizers. While in case of heavy texture soil like clay or silty clay it reduces the fixation of applied K fertilizers. Split application of K (half at transplanting + half at active tillering stage) in Trans-IGP, gave a yield advantage of 250 kg grains ha^{-1} compared with a single application at transplanting (Kolar and Grewal, 1989). Split application of K increased rice yields by 14.5% on silty clay loam soils (Pal et al., 2000). Similarly, at Raipur in Vertisol the

Table 3. Yield response to K application in rice.

Time and dose of K application	Location	Yield (kg/ha) or % yield increased	Reference
50% K_2O at tillering + 50% K_2O at panicle initiation	Tamil Nadu	K - 4609 R - 4549	Kamalanathan and Arivazhagan (2003)
100 kg K ha^{-1}		R - 33% K - 13%	Mondal et al. (1982)
	Pantnagar	12%	Dobermann et al. (1995)
90 kg K ha^{-1}	UP	-	Kumar et al. (2004)
Pre-plant and mid-season K applications	Missouri	-	David and Stevens (2005)
132 kg K ha^{-1}	Odisha	Jaya - 136% Pathara - 71% Mahsuri - 59% Parijat - 42%	Sahu (2001)
60 kg K_2O ha^{-1}	Odisha	-	Mitra et al. (2001)
Basal + panicle initiation	Raipur	-	Pandey et al. (1993)
Half at transplanting + half at active tillering stage	Trans-Gangetic Plains	250 kg grains ha^{-1}	Kolar and Grewal (1989)
38 kg K/ha - Three equal splits *viz*. at early tillering, active tillering and panicle initiation stages	Tamil Nadu	-	Ravichandran and Sriramachandrasekharan, 2011

K-*Kharif*; R-*Rabi*

splits application of 40 kg K_2O ha^{-1} half at basal and half at panicle initiation increased the grain yield (Pandey et al., 1993). The on-farm multi location trial in six districts of Pakistan showed that the split application of 62.5 kg ha^{-1} as 1/2 at basal and remaining 1/2 at 25 DAT increased yield (4.73 t ha^{-1}) and the increased grain yield of rice was attributed to the continuous supply of K during the crop growth period (Awan et al., 2007). Skipping of basal K_2O and application of 50% K_2O each to tillering and panicle initiation through MOP increased grain yield in *kharif* and *rabi* seasons (Kamalanathan and Arivazhagan, 2003; Arivazhagan et al., 2004). One step further, three equal splits *viz*., early tillering, active tillering and panicle initiation stages was beneficial in a high K soil (Ravichandran and Sriramachandrasekharan, 2011). Application of 33% of the total dose at sowing as a basal followed by two foliar sprays at flag leaf stage and at grain development was superior over 100% through soil application all at sowing (Narang et al., 1997). Hence, Annadurai et al. (2000) have concluded that K should be applied either as two splits (basal and panicle initiation) or three splits (basal, active tillering and panicle initiation) according to initial K status and type of soil for getting more response. Mondal et al. (1982) witnessed that the supply of 100 kg K_2O ha^{-1} along with 160 kg N ha^{-1} increased rice yields by 33% in the dry season and by 13% in the wet season compared to no K (control). Based on 60 on-farm trials in five districts across northern India, Singh et al. (2013) reported that application of K increased rice yield by 0.6 to 1.2 t ha^{-1}. In China, a foliar spray of 1% KCl three times at one-week intervals from heading stage of rice in cv. Wuyuegen was also beneficial for yield (Kadrekar, 1975). Potassium nitrate may also be used for foliar spray @ 2.5% at active tillering and at panicle initiation to increase rice productivity in India (Vijayakumar et al., 2019c). As a system management in rice-wheat cropping system, split application of recommended dose of K (RDK=60 kg K_2O/ha) in both rice and wheat, at 50:50 or 75:25 ratio over applying entire dose as basal enhanced the system productivity of by 8.2% (Vijayakumar et al., 2019b).

Effect of K application on rice grain quality

The hitherto focus of breeding programs, generally for productivity enhancement, shortening of duration and wide adaptability have shifted to grain quality (Zhang et al., 2004). In this context the role of potassium in improving grain quality (Usherwood, 1985) assumes significance. However, research in this direction is scattered in the literature. High levels of available K enhance the physical and nutritional quality of rice grain (Bijay-Singh et al., 2004). The K deficiency causes a reduction in grain yield and quality even long before the plant produces visible signs (Tiwari and Sulewski, 2004). This "hidden hunger" robs the profits from the farmers who fail to keep the soil K levels in the range high enough to supply adequate K at all times during the growing period. A deficiency of K for a short period, particularly during critical stages, can cause severe yield and quality loss.

K is required for every major step of protein synthesis since its formation is catalyzed by the enzyme nitrate reductase utilizing K (Patil, 2011). Despite of the availability of nitrogen in large quantity in plant the proteins are not manufactured when it is deficient in K. Under K deficit condition, "raw materials" (precursors) such as amino acids, amides and nitrate accumulate instead of protein formation. High concentrations of cellular K (about 0.1 M K) are required for protein synthesis (Evans and Wildes, 1971). In rice, a foliar application of 1% KCl at panicle initiation, boot leaf and 50% flowering stages, both in the monsoon and winter seasons, significantly improved the grain quality (Jayaraj and Chandrasekharan, 1997). While Mathad et al. (2002) could get a response for high protein content in rice @ 50 kg K_2O ha^{-1} cv. Jaya, hybrid rice responded up to 80 kg K_2O ha^{-1} (Dwivedi et al., 2006).

Rice K uptake and use efficiency

Rice needs a large quantity of K than N and more than 75% of which is retained by leaves, straw, and stover. The maximum K content is found in leaves and culms (about 70-75%) of rice, while very little K only accumulates in the milled grain (De Datta, 1981). It is estimated that the production of one-ton of rice grains needs at least 14.5 kg K in tropical and subtropical Asia (Witt et al., 1999). On contrary, Tandon and Sekhon (1988) reported 25.0 kg K uptake for each ton of grain yield. When the rice yield was less than 8 t ha^{-1}, it removed only 56-112 kg K and it exceeded to 200 kg K for more than 8 t ha^{-1} of grain yield (Dobermann et al., 1998). The removal of K from the soil by rice cultivation far exceeds the quantity of K added through the fertilizer and recycling. Singh and Singh (2000) reported that application of 60 kg K ha^{-1} along with 40 kg N ha^{-1} provided the highest K use efficiency and cost benefit ratio along with maximum N and K uptake in rice (cv. Saket 4)-wheat (cv. PBW 226) cropping system.

The foliar application of K accelerates the adsorption and assimilation of K and has the advantage of rapidly ameliorating the visual deficiency. Foliar application has also reduced the rate of K application and ensured even distribution of K. However, foliar fertilization is complementary to soil application and cannot replace the basal fertilization (Kafkafi et al., 2001; Vijayakumar et al., 2019a). Split application of K favoured greater adsorption of macronutrients and S in the grain as well as in the straw relative to the application of entire dose as a basal (Arivazhagan et al., 2004). Hybrid rice responded well to three splits of K application in terms of K uptake by grain and straw compared to other application times (Yadav et al., 2004). The rice absorbs more K^+ during the vegetative stage than the reproductive stage. Seventy-five percent of the total intake of K occurs before the plant reaches the booting stage and the remaining K^+ before the grain development stage. In general, the absorption of K occurs mainly at the vegetative stage and can reach a maximum of 10 kg ha^{-1} day^{-1} and even higher in cereals (Rameshkumar et al., 2003). Generally, cereal crops intake on an average of 1.5 times more K than N, but the application of K through inorganic fertilizer is much lower than N (Tandon, 2007). Hybrid rice (cv. MPH-501) N and K uptake and grain protein content have improved with increasing levels of N and K up to 160 and 90 kg ha^{-1}, respectively (Kumar et al., 2004). The increased application rate of K in salt-affected soils contributed to K uptake and decreased Na/K ratio, which improved plant growth, productivity and salt tolerance. Hybrid rice uptake more K than normal rice genotypes due to robust and vigorous root systems (Xu and Bao, 1995). Mathad et al. (2002) observed that K application at a rate of 50 kg K_2O ha^{-1} has significantly increased grain yield, protein content and produced quality straw.

Effect of K application on economics of rice

Lack of awareness of the economic benefits of K fertilization in rice is the main reason for low use of K fertilizers in India. In addition, the zero and sub-optimal application of K in the middle and lower Gangetic plains may be due to inadequate credit to farmers (Singh et al., 2013). Over the past few years, the cost of K fertilizer has been significantly increased. The steep raise in the price of K fertilizer has further aggravated its use in agriculture. Each rupee invested in fertilizer K produced an additional rice yield worth of Rs. 0.8 to Rs. 16, on the basis of on-farm rice trials in the IGP between 2009 and 2011 (Majumdar et al., 2012). A yield loss of over 500 kg ha^{-1} of rice was observed due to no application of K at more than 50% of the locations. It implies that such places, the application of K at a rate of 40-60 kg K_2O ha^{-1} will provide an excellent return on investment to the farmers and will mitigate mining of native soil K. Based on 60 field trials in five northern Indian districts, Singh et al. (2013) reported that the application of K increased the net return by 114 to 233 USD ha^{-1} and the rice yield by 0.6 to 1.2 t ha^{-1} as compared to farmer practice. Double split of recommended dose of K increased the net return (Rs. 85400 ha^{-1}), B: C (1.8) and return on investment (ROI) on K (Rs. 17.9 Rs^{-1}) of basmati rice over basal application of full dose of K (Vijayakumar et al., 2019a).

Water productivity and water use efficiency of rice

A decrease in water productivity, is a serious concern in rice farming (Humphreys et al., 2010; Hira, 2009; Bhatt and Kukal, 2014) where K could play a pivotal role by means of osmo-regulation (Zeiger, 1983). K alters the cell turgor pressure, which influences the cell elongation and the opening and closing of the stomata. The transport function of water and nutrients in the xylem and phloem of plants is regulated by K in conjunction with specific enzymes and plant growth hormones (Boyer et al., 1943a, 1943b; Evans and Sorger, 1966; Suelter, 1970, 1974). Once the K supply is reduced, the translocation of nitrates, phosphates, calcium (Ca), magnesium (Mg), and amino acids is lessened (Schwartzkopf, 1972). Thus, a sufficient quantity of K is indispensable for the efficient functioning of these systems (Thomas and Thomas, 2009). The mechanism of mitigating moisture stress in rice applying K is presented in Fig. 2.

Aerobic rice and K nutrition

In recent times, aerobic rice systems are promoted in South Asia, to minimize the water needs of rice by maintaining the soil at field capacity rather than flooded (Bouman et al., 2005; Vijaya Kumar et al., 2018). Dry seeding of rice with pre-monsoon rains (Humphreys et al., 2005) is the main requirement of this system of rice cultivation. Both the aerobic and direct seeded rice (DSR) systems are more prone to K deficiency compared to transplanted rice. Bhushan et al. (2007) recorded 19% irrigation water savings and 11% increase in water productivity with zero tilled DSR when irrigation was scheduled at 33 k Pa compared to puddled transplanted rice (PTR) with continuous flooding (CF) in a silty loam soil in Uttar Pradesh, India. On a sandy loam soil, Choudhury et al. (2007) observed a saving of irrigation water of about ~50% in DSR system irrigated at every second day in comparison with PTR with CF. Both irrigation and water input productivity were significantly higher in DSR than in PTR. The availability of K is relatively reduced in aerobic rice and DSR than in PTR because the K added by the irrigation water is negated, and the K availability is more under waterlogged soil than aerobic soil, it is therefore more vulnerable to K deficiency than the PTR. Applying K fertilizer to plants is a simple agronomic practice used to increase crop tolerance to a temporary moisture stress (Witold, 2013). Any improvement in K supply to plants during the period of mild water stress will escalate the root cells water uptake, which in turn increases its osmotic potential and thereby modifies the root depth by extending its length. Such growth, in turn, promotes access to other minerals (including N) and water, which promote plant growth and yield. The K application would also minimize the effects on rice growth, physiology and biochemical changes under cyclic water stress condition. Jákli et al. (2016) explained that potassium (K) enhances the crop water

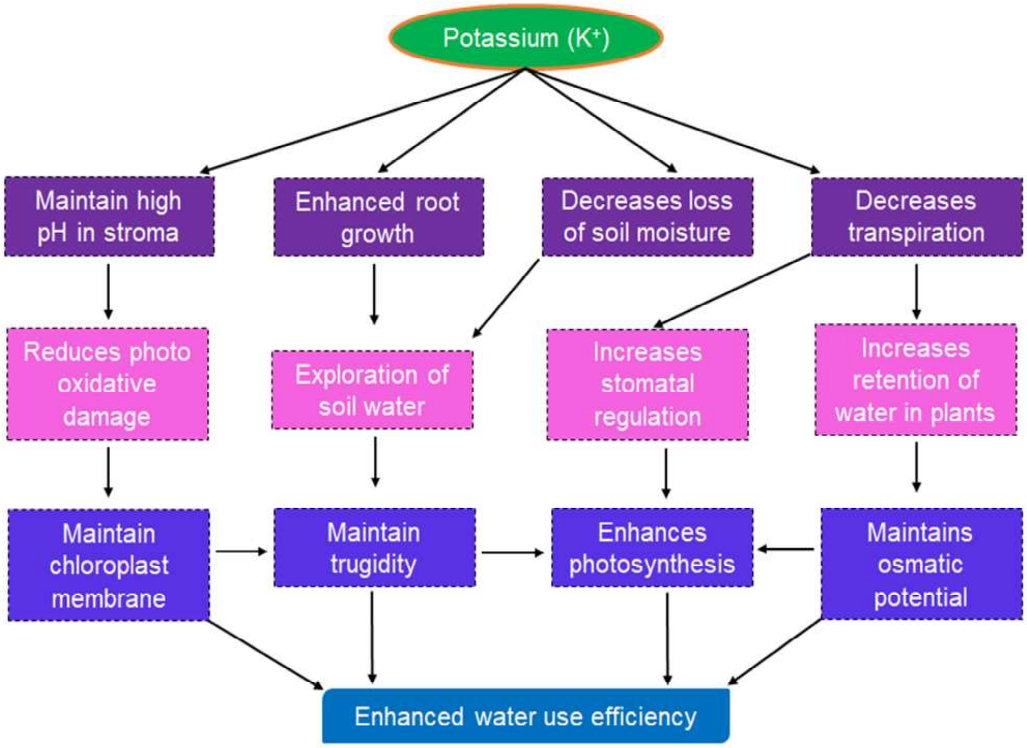

Fig. 2. Role of potassium under moisture condition [Modified from Waraich et al. (2011)]

use efficiency (WUE) and played a key role in alleviating plant moisture stress.

CONCLUSION

The increasing percentage of area cultivated in low - and medium - K content soils and the decrease in the use of K fertilizers pose an emerging threat to the rice-based cropping system. The rise in the price of K fertilizer after the implementation of the nutrient-based subsidy dwindled the balanced use of fertilizer nutrients in India. Growing evidence of increasing response to K application in rice and the mining of K nutrient in rice-based cropping systems demand the regular application of K. Sustaining rice yield without applying K fertilizer may pose a threat to the country's food and nutritional security. A larger part of the K removed by the rice crop is stored in the leaf and the culm (70%) while only a very small fraction is stored in the grain. Thus, retaining rice residue in the field could be the best option to maintain soil K, since rice residue (straw) is not utilized as cattle feed in many parts of the country and the cost of inorganic K fertilizer is also high. Split application of K during tillering and panicle initiation stage was found to have maximum advantages over the basal application. Aerobic rice and DSR systems are more susceptible to K hidden hunger. Adequate K fertilization in DSR and aerobic rice systems guarantees higher yield in addition to improving water productivity and nutritional quality of grains.

The K content of agricultural soil across the country is highly diverse and the blanket recommendation of K may not be appropriate. K is the chief fertilizers which governs balance fertilization. Thus, blanket recommendation of K should be replaced with soil test crop response based K application. Similarly, the use of decision support tool may be very effective in computing external K fertilizer requirement through computing K balance of the cropping system. Use of decision support tool may also simplify the difficult task of computing fertilizer rate for any given fertilizer source. Thus, there is a need to find out new efficient technique for K recommendation and it application in diverse soil type, crop and climate.

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