International Journal of Agriculture & Biology
ISSN Print: 1560–8530; ISSN Online: 1814–9596
16–406/2017/19–3–381–390
DOI: 10.17957/IJAB/15.0291
http://www.fspublishers.org

Review Article

Potash Use for Sustainable Crop Production in Pakistan: A Review

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Abstract

Pakistan is located in the sub-tropical zone and soils are deficient in a number of plant nutrients especially nitrogen (N) and phosphorus (P) including some micronutrients such as zinc (Zn) and boron (B). Apparently, country soils have high potassium (K) being rich in mica minerals but this high soil K does not account its availability for optimum plant growth as K bounded within minerals is not released to meet requirement for crop production. Nonetheless, some soils with low plant available K maintains its levels optimal for plant growth resulting in no response to K fertilization. Release and fixation of K depends on the type and content of soil minerals, based upon which, its distribution and retention properties are required to develop K fertilizer recommendations for sustainable nutrient management. Soil mineral composition and K chemistry also differ with development age and source of soil parent material. Use of K fertilizers in Pakistani agriculture is still under debate, due to diverse crop responses to K fertilizer. General K fertilizers recommendations are usually based on exchangeable K content in the soil and ignore the soil mineralogy and K dynamics which may lead to non-responsiveness of K applications. Nevertheless, K deficiency has been observed in many parts of the country. Recently farmers' interest to use K has improved with enhanced knowledge about the balanced fertilizers concept and technological development in fertilizers applications. Being a key macronutrient for plant growth and yield, K is taken up in higher amounts by all crops. Application of K fertilizers is therefore vital for sustainable agriculture growth in Pakistan, for which comprehensive research programs to endorse K fertilization by presenting a clearer picture of crop response to K application are needed. In wake up, soil mineralogy and K dynamics-based recommendations may be an effective tool to maximize crop yield in the country as the population increases at ~2.0% per year. In conclusion, (i) Pakistani soils require the use of potash to balance the fertilizer use for better crop yields, (ii) site specific recommendations of K fertilizers based on soil mineralogy and K dynamics in soil can deliver its economic returns, (iii) use of potash can enhance the quality of agricultural produce for international market, (vi) potash use can enhance the ability of crops to withstand environmental stresses in the climate change scenario.

Keywords: Potash; Precise fertilizer-use; Crop yield; Soil minerals; Produce quality

Introduction

Potassium (K) is an important macronutrient required in the highest amount after nitrogen for plants and its ample supply is crucial for crop productivity. Generally, K plays important functions in plant systems by activation of more than 80 enzymes involved in different metabolic processes including photosynthesis, protein synthesis, respiration etc., charge balancing across the membranes of different cell organelles, particularly plasma membrane and tonoplast, and as osmoticum in stomatal regulation by maintenance of guard cells turgidity (Mengel, 2007).

Existing potassium contents in earth's crust are more than 2.6% with micas and alkali feldspars as the major natural sources of soil containing 6–9% and 3.5–12% K, respectively. Typically, soil K exists in four fractions viz. mineral, non-exchangeable, exchangeable and soluble K (Sparks, 1987). Among these only soluble and exchangeable K are readily plant available and most of the fractions are fixed by clay minerals making it non-available for uptake by plants. This necessitates appropriate K fertilization to achieve optimum crop growth with good quality harvests.

Nonetheless, inadequate K fertilization is among the responsible factors for crop yield gaps in many parts of the world due to limited plant available K (Mengel, 2007), especially in developing countries. Further, soil K dynamics based on type and age of clay minerals play an important role in crop nutrition of potassium. To fulfill crop demand, usually higher K fertilizers are applied to achieve optimum growth but plants respond insufficiently to general fertilizer recommendations in soils rich with K-fixing clay minerals.

To cite this paper: Wakeel, A., H.U. Rehman and H. Magen, 2017. Potash use for sustainable crop production in Pakistan: A review. *Int. J. Agric. Biol.*, 19: 381–390

In a sandy clay loam soil of Michigan, about 92% of the applied K fertilizer was fixed and 1600 kg K ha^{-1} applied had significant response in tomato production (Doll and Lucas, 1973). The soil was rich in illite and vermiculite clay minerals with high cation exchange capacity (CEC) with major part of applied K as fixed making it immediately unavailable to the plants. Similar reports have been reported in other parts of the United States (Mengel and Kirkby, 2001). Recently, Wakeel *et al.* (2013) observed that presence of specific clay minerals affect the fixing and releasing capacity of K in three different soils. Smectite-dominant soils usually showed faster release of K than illite soils and poor response of sugar beet plants was found to K fertilization in these soil types (Bohn *et al.*, 2001; Wakeel *et al.*, 2013). Potassium sorption on exchange sites and its fixation also depend on the physicochemical properties of the soil along with the type and content of the clay minerals (Braunsweigh, 1980). Similarly, the age of soil developed from mica and alkali feldspar also determines the extent of weathering and K dynamics. Thus, during K take up, plants reduce its concentration in the immediate root zone, which releases K-ions from the minerals (Kuchenbuch and Jungk, 1984). In fact, the release of K converts micas to secondary 2:1 clay minerals-illite and then vermiculite (Farmer and Wilson, 1970; Havlin *et al.*, 1999; Fig. 1). Further, some fractions of applied K to illite and vermiculite rich soils K may get fixed by soil particles making it unavailable or slowly available to plant roots (Scott and Smith, 1987). Nonetheless, K in fixed fractions may become available to plant roots when released into soil solution particularly at low soil K levels (Cox *et al.*, 1999), but is too slow release may not meet the plant-growth requirements.

Use of potash fertilizers is very low in agriculture which limits the crop growth, yield and quality. There are several reasons for low usage and K fertilization may increase economic crop production. Several reviews already available highlights the importance of potassium uses in agriculture (Zorb *et al.*, 2014), potassium use efficiency in different crops and genotypes (Rengel and Damon, 2008), strategies to improve potassium use efficiency (Shin, 2014), potassium transport and signaling (Wang and Wu, 2013; Luan *et al.*, 2016), potassium homeostasis to improve biotic and abiotic stress (Anschütza *et al.*, 2014; Luan *et al.*, 2016) and genetic approaches to improve potassium uptake and utilization efficiency (Wang and Wu, 2015). Here in present review we discuss the significance of K fertilization, reasons for low K usage, economics of its fertilization in arable and irrigated crops, current status of K research and possible directions to enhance its application to lessen the yield gaps for sustainable crop productivity particularly in context of Pakistan.

Significance of Potassium Fertilization in Pakistan

Agriculture is the mainstay for ever increasing population of Pakistan. It contributes about 23% to country's total GDP with about 50% of labor force engaged. Agriculture depends on natural resources and climatic conditions and as dynamic system it requires excellent planning for sustainability. Green revolution was a great break through world-wide to fulfill the food requirement of huge population of the world; Pakistan was also among the active participant of green revolution of 1960s with drastic increase in food grain production. With Green revolution, introduction of high yielding varieties and fertilizers responsive crop varieties, a significant increase in food production was observed (Fig. 2). There was a continuous increase in yields of cereals since green revolution, however these gains have been static since last decade with no significant increase, despite crop varieties have still great potential to yield more by efficient use of inputs and management practices.

Since green revolution, continuous usage of nitrogenous and phosphatic fertilizer has been increased in Pakistan but of K is almost negligible. Critical comparison of fertilizer use with yield increase reveal that instead of increase in N and P fertilizers, the average gain in crop productivity is stagnant since last decade and neglected K fertilization may be one of responsible factors for stagnant productivity, because balanced use of fertilizers is crucial for maximum, economical and sustainable crop production. With increase in nitrogenous fertilizers usage, the ratio of K: N fertilizer has decreased severely from 1994 to onward contributing to less economic agricultural returns (Fig. 3).

The available, soluble and exchangeable, K fractions have been reduced in Pakistani soils due to cultivation of high yielding crop varieties and no inputs of K fertilizers. With high crop demands for K, there is also plausibility of its depletion from these soil fractions. Based on average production of crops, Pakistani soils are removing 100–150 K_2O kg ha^{-1} per year. The data provided by soil fertility research institute also revealed obvious decrease in available K under different cropping systems (Fig. 4). Therefore, severe deficiency of K is expected in coming years with more depletion if K use in fertilization practices is neglected and even soil fertility may be at alarming risk of sustainability.

Use of Potash Fertilizers

Since the green revolution in 1960s, use of chemical fertilizers was promoted in Pakistan, as in many other parts of the world. In beginning, with nitrogenous fertilizers, phosphatic (P) fertilizers were introduced later in 1970's and the use was increased over time (Fig. 5). Since the times, use of nitrogenous fertilizers was significantly higher with the plausibility of better, quick and more cost-effective crop response for crop yields and therefore at present, nitrogenous fertilizers contribute 78% to total fertilizer use in Pakistan (NFDC, 2015). Slow and steady increase in P fertilizer usage sustained and since

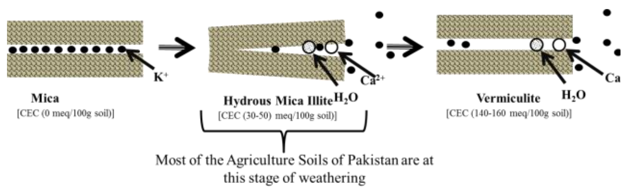


Fig. 1: Properties of clay minerals developed from micas and often present in agricultural soils. Pakistani soils are dominant in illite/hydrous mica with considerable amount of K and cation exchange capacity, however vermiculite have also been reported in a small area (adapted from Wakeel *et al*., 2013)

last few years until 2013–2014, its use has been reduced due to higher prices of P fertilizer. Pakistan's soils contain mica with K concentration of ~7%; however, plants' requirements of this mineral are not fulfilled due to less plant-available potassium. Potassium application has been discouragingly low in all the major crops, except for potatoes, where farmers use potash fertilizers for better yields and improved tuber quality.

About 50% of total fertilizer-offtake in Pakistan shows possibly its applications in wheat due to more certainty of economic returns (Fig. 6). Cotton is the second most fertilized crop and occupies 25% of total fertilizer use. Other crops have not been fertilized to a great extent except potato in which utilization of K fertilizer is greater than any other crop in Pakistan.

Many efforts have been made by government, national and international fertilizers associations, but the use of potash in agriculture crops have remained miserably low. Average use of fertilizers per hectare is 132 kg for N and 32 kg for P fertilizers, whereas for potassium is less than 2 kg ha^{-1} instead of higher recommendations for many crops in Pakistani soils (Table 1). Imbalanced fertilization is always uneconomical and very small ratio for K to N results into several problems, such as crop lodging particularly in rice and wheat. Recently, we found improved stem strength in rice with balanced use of K and N by decrease in basal internode length (Zaman *et al.*, 2015). Although, with introduction of compound fertilizers, such as NPK has increased K fertilizer use in field crops to some extent, but situation has grown up with the dilemma of reduced K_2SO_4 (SOP) availability in the market and worsen with rare SOP availability. Nonetheless, over the last few years, potassium containing liquid fertilizers have been introduced in the market by various private companies and are recommended as fertigation or foliar but their adaptability by farmers is very low. Moreover, application of these K fertilizers with active ingredient in small amount cannot fulfill crop requirements.

A recent development has been observed with the import of KCl (MOP) as alternate to SOP by national fertilizer companies, which is economical and may help to improve potash use in Pakistan due to its low price (~ 2/3 of SOP) and with greater acceptability among farming community. However, long term consequences are required to analyze the situation with addition of chloride (Cl^-) by use of MOP under Pakistani conditions.

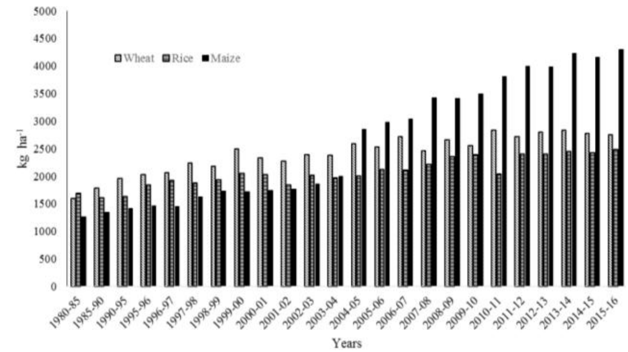
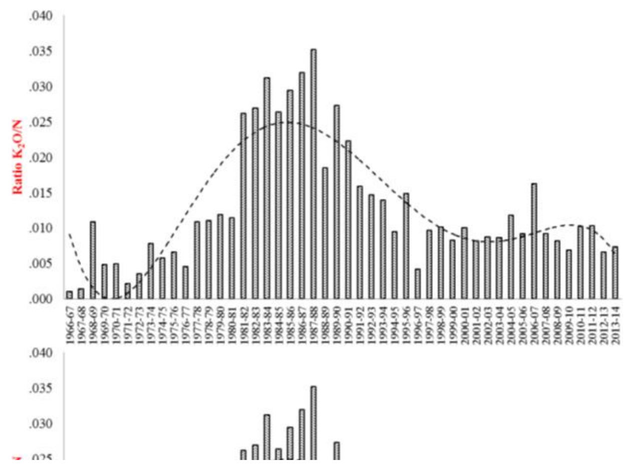


Fig. 2: Yearly trend of per hectare yield of wheat, rice and maize starting from 1980 to 2016 (Anonymous, 2016)



Economics of Potassium use in Arable Crops

The profitable use of K in different crops depends on costs of inputs especially fertilizers, increase in crop yield and appropriate support price of produce (Ahmad and Muhammad, 1998; Majumdar *et al.*, 2012). Concept of balanced use of fertilizers involves not only increase in physical output of crop and also maximizes profitability in terms of economic returns for every unit of fertilizer applied. Increases in economic returns or value cost ratio may decrease when fertilizers use tend to be balanced (Table 3), therefore, growers should consider use of inputs and outputs in such a balanced manner that specific input costs are administered in economical way especially with considerable increase in K fertilizer prices. Very few studies highlight the economics of K fertilizers as increase in net returns or value cost ratio and showed that crops response to applied K is highly variable and due to different agro-ecological zones of country, response depends on soil type, previous crop history, soil nutrient capacity and specific crop nutrient requirement even use of K-efficient genotypes

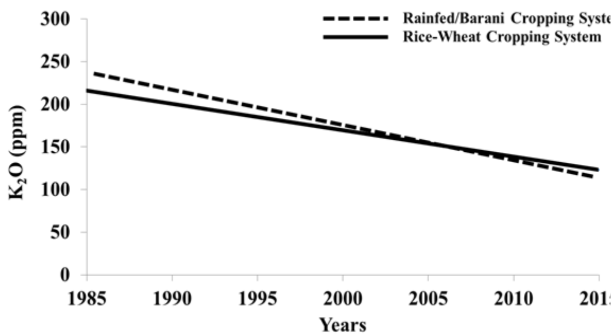


Fig. 4: Depletion of potassium from soil in two different cropping systems in Punjab (Soil Fertility Research Institute, Punjab, Pakistan, 2014)

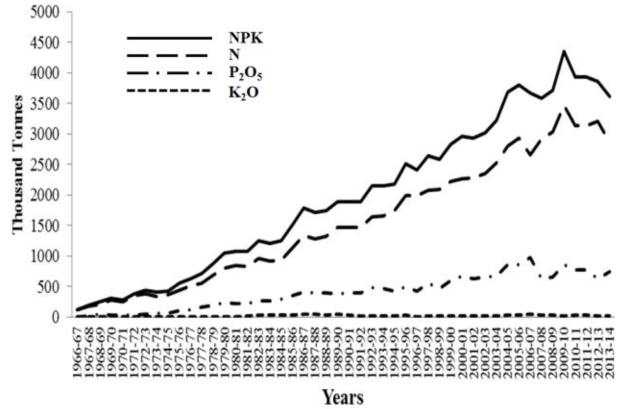


Fig. 5: Chronological off take of N, P_2O_5 and K_2O in Pakistan (source: NFDC, 2015)

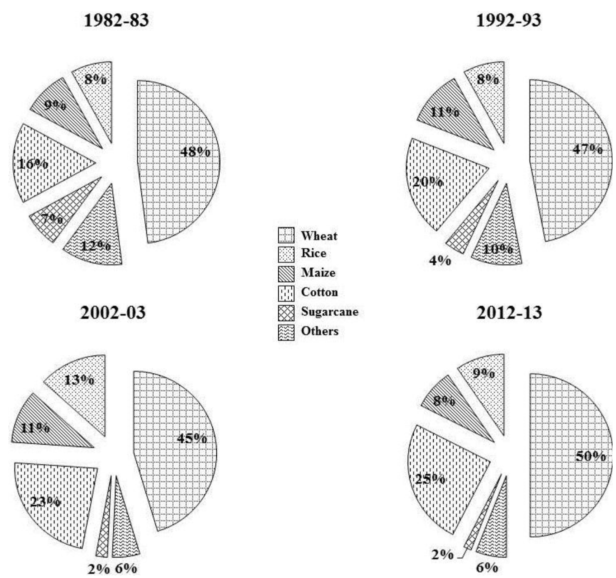


Fig. 6: Use of fertilizer (% of total) for various important crops in Pakistan. A chronological view (NFDC, 2015)

(Table 3). The use of K specifically in arable crops of rain-fed area can be high due to reduced release or its availability from soil and in case of irrigated crops; K gradient from canal irrigation should be measured and considered in K fertilization practices (Ahmad *et al.*, 2014). This may not only help to reduce the K requirement but also the economical use of fertilizers. Under low K or deficient soil conditions, growing of K efficient genotypes may improve the K use efficiency (KUE) for sustainable crop production (Hassan *et al.*, 2014).

Causes of Low Use of Potassium Fertilizers

Mica based rich soils; however, due to continuous weathering, intensive cropping and soil mineral-K release, these have been converted to illite and vermiculite-dominant clay minerals. High yielding crop varieties mine the soil for K, without being replenished by application of K fertilizers. Small land holdings of Pakistani farmers with limited financial resources not allow them to use high price potassium fertilizers.

Lack of Awareness about Balanced Fertilizer Use Concept

Poor education and lack of awareness about the balanced fertilization is one of reasons for low potassic fertilizers use among growers. No Farmer's education program is available to create awareness about balanced fertilization. Participatory approach can be advantageous to increase potash use, because the effectiveness of this approach was visible in the very high increase in nitrogen use during the early part of green revolution. Likely, increase of diammounium phosphate (DAP) increased among farming community with better and positive response on plant growth and yield as compared to single superphosphate (SSP) and triple superphosphate (TSP). Another possibility for better response towards DAP may be of its N gradient contributing towards its acceptability. Slow crop response to K fertilizers than N and P may be one of possible reasons for its low off-take. Further, soil response to applied K is different than N and P which is diverse (Wakeel *et al.*, 2013). Farmers' education about potassium application and its effects on different crop mechanisms and productivity are needed. A good example is reduction in negative effects of abiotic stresses with K nutrition (Cakmak, 2005) such as drought, salinity and frost. This may also function to attract farmers towards balanced fertilizer use.

K Gradient Supply from Canal Irrigation Water, a Misconception

Canal water is good source of K, however there is misconception among farming community that potash

Table 1: Fertilizer recommendations provided by Punjab Agriculture Department for major crops of Pakistan

Crops	Nitrogen kg ha^{-1}	Phosphorus	Potassium
Cotton	200-400	88-175	95-125
Wheat	80-130	58-115	62
Rice	85 -172	68-102	62-80
Maize	250	115-172	62-125
Potato	250	125	125
Sugarcane	172-300	58-172	62-125
Sugar Beet	125	125	150
Oilseed Crops	32-88	32-88	32-62
Sunflower	150	100	65
Kharif Fodders	58	58	32

Source: http://dai.agripunjab.gov.pk/croptechnologies

Table 2: Response of potassium fertilization in different crops grown on Pakistani soils

Crop	Soil K Status	K Source	Application rate of K application	Application method	Increase over control	Reference
Maize	92 mg K kg^{-1} soil	K_2SO_4	60 kg ha^{-1} 90 kg ha^{-1}, 120 kg ha^{-1}	Soil	10% shoot growth 19% shoot growth 20% shoot growth	Khan *et al.* (2015)
Wheat	-	K_2SO_4	60 kg ha^{-1}	Soil	39% shoot K concentration at booting and milking stages	Majid *et al.* (2007)
Sugarcane	-	K_2SO_4	42 kg ha^{-1} 84 kg ha^{-1} 126 kg ha^{-1} 168 kg ha^{-1} 210 kg ha^{-1}	Soil	73% yield 101% yield 127% yield 190% yield 187% yield	Soomro *et al.* (2014)
Wheat	80 mg K kg^{-1} soil	K_2SO_4	60 kg ha^{-1}	Soil	13% yield	Khan *et al.* (2007)
Tomato	-	KNO_3	500 ppm	Foliar	39% shoot growth	Azeem and Ahmad (2011)
Wheat	0.3 mmol L^{-1} soil solution	K_2SO_4	50 kg K ha^{-1} 100 kg K ha^{-1}	Soil	14% grain yield 30% grain yield	Hussain *et al.* (2013)
Wheat	-	K_2SO_4	30 mg kg^{-1}	Soil	49% K concentration in leaf under salinity	Saqib *et al.* (2008)
Tomato	97 mg K kg^{-1} soil	KNO_3	3.3 mmol kg^{-1} soil, 4.5 mM Foliar 6.6 mmol kg^{-1} soil, 9 mM Foliar	Soil and foliar	18% shoot growth when applied to soil; 12% shoot growth when applied as foliar spray 27% shoot growth when applied to soil; 23% shoot growth when applied as foliar spray	Amjad *et al.* (2014)
Wheat	-	K_2SO_4	60 kg ha^{-1}	Soil	12% shoot growth	Akhtar *et al.* (2000)
Cotton	-	K_2SO_4	30 mg pot^{-1}	Soil	8, 34 and 46% shoot K concentration under 70, 140 and 210 mol m^{-3} NaCl stress, respectively	Akhtar *et al.* (2010)
Wheat	115 mg K kg^{-1} soil	K_2SO_4	80 kg K_2O ha^{-1} 120 kg K_2O ha^{-1}	Soil	55% yield 160% yield	Ashraf *et al.* (2011)
Wheat	86 mg K kg^{-1} soil	KCl	75 kg ha^{-1} 150 kg ha^{-1} 225 kg ha^{-1} 300 kg ha^{-1}	Soil	6% shoot growth 16% shoot growth 29% shoot growth 27% shoot growth	Saifullah *et al.* (2002)
Sugar beet	0.3 mmol L^{-1} soil solution	K_2SO_4	75 kg ha^{-1} 150 kg ha^{-1}	Soil	15% yield 50% yield	Hussain *et al.* (2014)
Cotton	-	KCl	62.5 kg ha^{-1} 125.0 kg ha^{-1} 250.0 kg ha^{-1}	Soil	30% shoot growth 64% shoot growth 83% shoot growth	Pervaz *et al.* (2006)
		K_2SO_4	62.5 kg ha^{-1} 125.0 kg ha^{-1} 250.0 kg ha^{-1}		32% shoot growth 69% shoot growth 86% shoot growth	

fertilizers are not required in soils supplied with canal irrigation water. Potassium gradient in canal water can be complementary to soil applied potassium fertilizers particularly under irrigated conditions, but can't fulfill the crop requirement to achieve high yields. Continuous cropping without K or organic matter inputs since decades have contributed to soil-K mining particularly with cultivation of high yielding varieties due to very high population pressure. With climate change phenomenon and silting of water reservoirs, canal water supplies are being limited and therefore crop must be supplemented with ground water. With increasing use of ground water that contain very small gradient of K as compared to canal water will reduce its addition to soils posing alarming threat to agricultural sustainability of country.

General Crops Fertilizers Recommendations

Fertilizers application should be always based on soil nutrient status. In Pakistan, generally, fertilizers recommendations are provided by the provincial

Table 3: Economics of K fertilizers use for different crops in Pakistani soils

Crop	Soil K Status (mg K kg^{-1})	K Source	Rate of K application (kg ha^{-1})	Soil Type	Increase in yield over control (%)	Economic returns (%)/Benefit: cost Ratio	Reference
Wheat	139	-	30	-	3.82	-0.88	Tahir *et al.* (2008)
			60		9.23	16.85	
			90		10.67	-0.001	
Wheat	135, 135 and 160	KCl	37	Alkaline, calcareous and clay loam	15.78	31.77	Bakhsh *et al.* (1986)
			74		2.94	1.51	
			111		-1.49	-10.57	
			148		2.04	-5.33	
Wheat	135, 135 and 160	K_2SO_4	37		3.58	4.10	
			74		14.88	45.26	
			111		8.02	6.41	
			148		6.25	-1.07	
Sunflower	121	K_2SO_4	25	Alkaline, calcareous and clay loam	9.20		Amanullah and Khan (2011)
			50		12.79		
			75		30.13		
			100		18.20		
			125		5.66		
Rice (wheat-rice system)	80	K_2SO_4	60-0	Silty clay	30.95	2.5:1	Khan *et al.* (2007)
			0-60		47.35	3.9:1	
			60-60		49.98	2.0:1	
			30-30		37.69	3.1:1	
Canola	131	K_2SO_4	25	-	18.18	21.83	Khan *et al.* (2004)
			50		22.78	25.64	
			75		25.65	27.48	
			100		28.20	28.53	
			125		32.53	32.50	
			150		34.35	32.55	
Maize	65	MOP	50	Silt clay loam	16.40	1.5	Tariq *et al.* (2011)
			100		33.30	4.8	
			150		36.34	3.6	
		K_2SO_4	50		17.23	2.3	
			100		33.34	3.3	
			150		35.47	2.5	

agriculture department. Due to least soil testing facilities, farmers usually don't analyze their soils and general trend of fertilizers application are practiced. Site-specific fertilizer recommendations are very rare and at district level, soil fertility laboratories established by provincial governments are not enough to meet farmer's requirements. Usually, N and P general recommendations are followed, but for K, these recommendations often result in poor crop response due to variations in soil mineralogy and K dynamics. This may be one of plausible reason among growers for low potash application and hence, difficult to get positive response to apply additional amount of fertilizers without any gain in income.

Fertilizer Prices and Availability of K Fertilizer

With small land holdings (~2 hectares), limited financial resources are constraints for farmers to go for balanced fertilizer use. On other hand, high costs of potash restrict its use by farmers when they are already spending a lot on N and P fertilizers. Many available reports available highlights the importance of K fertilization in country for sustainable and economic agricultural productions, but escalating prices of K fertilizers is a big constraint for balanced fertilizer use. Poor interest of government and no aggressive campaign by fertilizer industries for K fertilization have embarrassed the situation. Subsidizing agriculture inputs especially fertilizers including K can be of top importance to increase its use. The paramount example is of increased use of nitrogen when urea subsidized in early green revolution, even until now nitrogenous fertilizers consumption is high even after withdrawal of subsidy. Such significant measures should be considered for K increase and to propagate its use at farm level. Another reason for limited K application in agricultural crops is that very few groups of fertilizers suppliers are involved in this business and thereof had least availability of K in the country.

Instability in Market Prices of Agricultural Produce

Economic values of agricultural inputs and stabilized support price of agriculture produce are main drivers for balanced fertilization. The prices of agricultural inputs are more instable than agricultural produce which creates uncertainty in economic returns limiting the farmers' choice to use agricultural inputs. Existing rice and cotton support prices are creating frustration due to loss is farmers' income despite huge expenditures on purchase of inputs. In such scenario, adoption of recommended agricultural practices among small landholders is reduced.

Potassium Research in Pakistan

Main research focus on potassium in Pakistan agriculture has been to improve the crop productivity and very few studies highlight prospects of soil applied K in different cropping systems and its role in reducing the devastating effects of biotic and abiotic stresses.

It is believed that country's soils could supply sufficient K required for plant growth. However, recent soil analyses have shown a significant decrease in soil K status (Fig. 4) and a considerable research data available indicate that most of crops respond to K fertilization (Gurmani *et al.*, 1986; Khattak and Bhatti, 1986; Ranjha, 1995; Mian *et al.*, 1998; Akhtar *et al.*, 2002; Tariq *et al.*, 2011). Nonetheless, some studies also report no significant improvement in crop yields with K application despite high apparent crop potential (Bajwa, 1985; Akhtar and Dixon, 2013) suggesting crop response may be specific with diverse mineralogy and K dynamics of the soil.

Fixation of K by different clay minerals has been considered as one of the reasons for reduced crop response to K fertilization. Mehdi and Ranjha (1995) found that K fixation increased with the K fertilization, but it was high in fine textured soils than coarse one. Khattak (2002) reported that that amount and type of clay minerals result in fixation of added K as well as recovery of non-exchangeable soil K. Soils differing in clay mineralogy also vary in response to applied K (Akhtar and Dixon, 2013). For instance, smectite types of clay minerals in Lyallpur soils usually don't respond to added K required for optimum plant growth. And K fixation does not directly depend on total clay content but with the types of clay mineral in the soil present (Awan *et al.,* 1998a). Nonetheless, clay content and the weathering of parent material have a strong relationship with extractable potassium (Awan *et al.,* 1998b). Linear response of potassium addition was observed on maize growth in sandy clay loam and sandy loam as compared to clay loam soils where applied K response reduces, perhaps due to its fixation or presence of sufficient K in soil (Wakeel *et al*., 2002).

During early profile development, long-term fertilizer effect on K-fixation in the soil has not been observed. However, marginal changes in soil plant available K and in the mineral composition had been observed with less K fertilization in the canal irrigated cotton-wheat system (Sheikh *et al.,* 2007). Bhatti (2011) concluded that for promotion of K recommendations should be based on K-fixing capacity and clay mineralogical composition of soils. Clay mineralogy is strongly related with the profile development and weathering stage of the soils and later may have a significant role in determining the K availability.

Due to K role in biological systems, various studies on ameliorating effect of K application under salt and drought stresses are also available. These studies employed different physiological traits with few highlights on grain yield. Foliar applied potassium improved the plant growth and grain yield in wheat under saline conditions (Khan and Aziz, 2013) and foliar fertilization may be more effective in soils with K-fixing clay minerals. Application of potassium sulphate improved crop yield by mitigating the toxic effect of Na^+ and it was concluded that K supplementation can be an effective tool for optimum crop production in saline and saline-sodic soils (Hussain *et al.*, 2013).

Beneficial effects of K fertilization were observed in maize under salt stress when a decrease in Na^+ and NH_4 toxicity was observed in hydroponic culture (Yousra *et al.*, 2013). Potassium stimulated maize growth under saline conditions was attributed to increase CAT activity, higher photosynthetic capacity and increased K concentration in plant leaves (Abbasi *et al.*, 2014). Nonetheless, potassium applied mitigation in adverse effects of drought have also been reported in maize (Zhang *et al.,* 2014). In another study, Kausar and Gull (2014) reported improved wheat biomass and calcium (Ca), magnesium (Mg) and phosphorus (P) uptake K application under salt stress. Thus, it may be suggested that K fertilization can be very helpful for crop production under salt and drought stress conditions with un-predictable rain-fall and reduced canal water supply. Response of Potassium fertilization response in different country soils had been reported by many researchers for which details are given in Table 2.

Future Research Outlooks

Despite of well recognized facts of K in sustainable crop production, its application has been continuously ignored. A solid research and awareness plan is urgently needed to promote K application for which precise K recommendations and produce quality should be prioritized.

Precise Potash Recommendations

The soil physicochemical properties and K forms present in the soil has evidence with different clay minerals (Surapaneni *et al.,* 2002; Srinivasarao *et al.,* 2006). Sharpley (1989) found a strong relationship between clay mineralogy and potassium forms in the soil and suggested its function to predict soil fertility and potassium uptake by plants. Bhatti (2011) concluded that K fertilization in Pakistan should be based on soil K-fixing capacity and clay mineralogical composition due to varied response of clay mineralogy to applied K (Akhtar and Dixon, 2013). Precise fertilizer recommendations based on soil mineralogy and K dynamics can be more effective tool cost-effective use and management of K fertilizers. A large number of soil series based on physicochemical properties are present in Pakistan, however only few are dominant and covers ~70–80% of agricultural land. . Analysis of these dominant series for soil mineralogy and K dynamics may provide useful data for precise K recommendations.

Potassium for Produce Quality

One of most striking role of potassium is to enhance crop quality and define produce quality as primary plant nutrient is well established (Pettigrew, 2008). Synthesis of photosynthates and their translocation is directly affected by K deficiency in crops deteriorating the quality of fruits, grains and vegetables. In citrus, K affect the fruit size, peel thickness, sweetness and color of the fruit (Alva *et al.*, 2006). It improves the weight per kernel in corn, oil contents in soybean, milling and protein quality of wheat (Mengel and Kirkby, 2001). Potassium also improves the quality of cotton fiber, sugar content in sugar cane and sugar beet. In addition to improving physical quality, K increases disease resistance and the shelf life of fruits. Quality can also be affected indirectly due to lodging in K deficient crops and its fertilization improved lodging resistance by increasing stem strength (Zaman *et al.*, 2015). Nevertheless, plants resist against wilting and winter kill of alfalfa is also improved by K fertilization.

In Pakistan, very little intention has been given to the quality aspects of agricultural produce. Due to competition in global market, produce quality is very important to consider for export of agriculture commodities. Produce quality based price and export reflects the needs for balance use of fertilizers, especially potash. Sugar cane with increased sugar contents with use of potash may have more economic value.

Soil Sustainability and Abiotic Stresses

Application of potassium to improve plant growth and yield is well propagated at different forums in Pakistan, however, its use to combat environmental stresses and sustainable crop production is not exemplified. In arid and semi-arid regions, water is major limiting entity for plant growth and prolonged exposure to drought may damage the plants by production of reactive oxygen species (ROS). Adequate supply of K improves the osmotic adjustment and develops tolerance in plants to water deficit (Egilla *et al.*, 2005). Likely, many researches on potassium function to improve salt stress are available (Cakmak, 2005; Ashraf *et al.*, 2012; Wakeel *et al.*, 2013). Potassium minimizes the detrimental effects of sodium (Na) under salt stress by improving K: Na ratio in plant tissue and plant cell (Wakeel *et al.*, 2013). It also improves plant resistance against waterlogging and low temperature stress (Wang *et al.*, 2013). However, practical implications of plant improved stress resistance still missing that should be explored under local soils and environmental conditions for sustainable crop production. Moreover, K fertilization is important for soils with respect to nutrient depletion that is very much higher in case of K as compared to negligible addition of organic or inorganic sources. Severe K deficiency effects on crop yield may be higher in future if the soils are not provided with sufficient amount of potash.

Use of Potassium Chloride in Pakistan Agriculture

Potassium sulfate (SOP) is usually recommended for Pakistani soils due to extra benefits of sulfur addition; however, high increase in SOP price in past few years has made it out of reach of Pakistani farmers. With local market potential, the fertilizer industry has started to import potassium chloride (MOP) due to its low price. Use of MOP in Pakistani soils is safe and beneficial for crops without any residual accumulation of Cl^- in the root zone (Shafiq and Ranjha, 1998; Ghaffar *et al.*, 1999; Tariq *et al.*, 2011). However, long term and comprehensive studies are needed to find out the residual effects of MOP and Cl^- on quality of produce and Cl^- accumulation into soils.

Conclusion

The available information indicates that most of the Pakistan agricultural soils require K fertilization because many of these are deficient in it and other are at margins. Due to negligible use of potash in Pakistan soils since decades, it has been depleted from the soils, especially grown with intensive cropping and high yielding cultivars. For sustainable crop production, it is very important to apply potash. Well-planned efforts are required to highlight the significance of potash in agriculture possibly by, (a) promoting agricultural advisory services and progressive farmers to create the awareness about the benefits of potash, (b) providing a clear message to policy makers for possible subsidies to attract the farmers for its use, (c) precise K fertilizer recommendation based on soil mineralogy and K dynamics in the soils for better economic returns, (d) improving the produce quality for export and providing better prices to farmers based to enhance K content and quality of produce. However, research on comparative studies of MOP and SOP are still needed to investigate the Cl^- dynamics in the system and its possible effects on produce quality.

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(Received 04 August 2016; Accepted 11 February 2017)