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Editorial

Dear readers,

The latest issue of IPI's *e-ifc* newsletter provides reports from Bangladesh, India and Pakistan. In all papers, researchers are striving to make the most efficient use of potassium (K).

Soil tests for K have been used for decades. But, as soils vary from place to place, sometimes within a very short distance, different soil extraction methods are needed in order to correctly assess soil K availability for plants. In some parts of the world, soil analysis is hardly used, and instead farmers are given a blanket recommendation which, in many cases, does not meet the crops' demand. In other regions, soil analysis is available, but its cost and adaptability to crop needs is not precise enough. Yet, when soil K analysis is properly performed for both capacity and intensity of soil K, the results obtained provide reliable K fertilization advice.

We expect that new technologies will provide better procedures for analyzing K needs in plants. Farmers around the world need to make the most reliable analysis in order to use resources efficiently and cost-effectively, and we at IPI are investing to help them achieve this goal.

I wish you an enjoyable read.

Hillel Magen
Director

Photo cover page: IPI-IAS potash experiment in rubber, Vietnam. Photo by IPI.

Research Findings

Turmeric field in Tamil Nadu, India. Photo by P.K. Karthikeyan.

Response of Turmeric (*Curcuma longa*) to Potassium Fertilization on K Deficient Soil in Northern Bangladesh

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Abstract

Field experiments were carried out over two growing seasons (2010/11 and 2011/12) to study the effect of potassium (K) fertilization on turmeric (*Curcuma longa*) on a light textured K deficient soil (Terrace Soil if the Level Barind Tract, AEZ 25) at Shibganj, Bogra, at the Bangladesh Agricultural Research Institute's (BARI) Spices Research Center (SRC) (Latitude 24°51'0 N, longitude 89°22'0 E, and elevation 23 m). The work was carried out to establish the optimum application rate of K to maximize yield and nutrient uptake of turmeric (var. BARI Holud-3) and to draw up a K balance sheet for K utilization by the crop. Five treatments were compared including a control without K application: T_1=K_0 control, T_2=K_{40}, T_3=K_{80}, T_4=K_{120} and T_5=K_{160} kg ha^{-1}. Potassium chloride (muriate of potash, MOP) was used as the source of K. The plots were laid out in a randomized complete block design (RCBD), each treatment with three replicates. A blanket dose of $N_{133}P_{18}S_{13}Zn_2$ kg ha^{-1} was given to all plots.

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Application of K significantly increased (R^2>0.9) rhizome yield up to 37.2 and 26.3 t ha^{-1} in 2010/11 and 2011/12 respectively, both with the application of 160 kg K ha^{-1}. Yield attributes of turmeric also improved with increased K application. K application increased yield by 39 and 52 percent (in 2010/11 and 2011/12 respectively). The amount of K taken up by turmeric increased in response to raised levels of K application up to 160 kg K ha^{-1} ranging from 68-180 kg K ha^{-1}. An apparent K balance was estimated on the basis of K added through fertilizer and K uptake by the turmeric. This K balance was found to be negative in all the treatments in the study area. Among the K levels used, 160 kg K ha^{-1} was found to be economically most profitable, contributing an additional income of approx. USD 2,200 to 2,600 per hectare. Considering the linear response of yield to applied K along with the economic returns, the application of K at 160 kg ha^{-1}, along with a blanket dose of $N_{133}P_{18}S_{13}Zn_2$ kg ha^{-1}, appears to be the best-suited dose for maximizing the yield of turmeric in K deficient terrace soil in the Level Barind Tract (AEZ 25) soil. However, the observed negative K balance, even when other nutrient supply is balanced, as well as the findings of linear response in yield, high agronomic efficiency (AE) for applied K, and the insensitivity to K cost, all suggest that there is scope to increase K and possibly nitrogen (N) and phosphorus (P) application levels to achieve even higher yields and profitability.

Introduction

Fertile soil is an important natural resource for any country. It is important therefore that Bangladeshi farmers try to obtain higher yields while managing soil fertility through judicious use of fertilizers to achieve sustainable crop yields. In Bangladesh, however, soils are being exhausted due to the increase in cropping intensity and the introduction of high yielding varieties and new technologies. Available data indicate that the fertility of most Bangladeshi soils has deteriorated (Ali *et al.,* 1997 and Islam, 2008) which is responsible for the stagnation and in some cases, decline, of crop yields. The use of chemical fertilizers mainly to supply Nitrogen (N), Phosphorus (P), Potassium (K) and Sulphur (S) has been increasing steadily but these fertilizers have not been applied in balanced proportions which has led to a depletion of constituent nutrients. Annual rates of depletion of N, P, K and S in areas under intensive cultivation range between 180 and 250 kg ha^{-1} yr^{-1}. Potassium is the third major plant nutrient following N and P. Analysis of nutrient use ratio shows that K use is low and it is for this reason that K deficiency is identified as deficient in most soils in Bangladesh (Noor *et al.*, 1998).

It was commonly believed that adequate amounts of K were present in Bangladeshi soil to meet crop demand. While this might have been true for local crop varieties with low yield potentials, major crop intensification that has occurred in recent years has placed a higher demand on K supply, rendering crops more susceptible to K deficiency. Despite the growing consciousness of farmers of the beneficial effect of applying K together with N and P, there is widespread K deficiency which has been reported on a variety of crops. These include potato, sweet potato and other root crops, sugarcane, fruit, onion, garlic, fiber crops and high-yielding variety (HYV) cereals (Islam *et al.*, 1985; Kundu *et al.*, 1998; Noor *et al.*, 1993; Miah *et al.*, 2008). In terms of unit nutrient requirement, K is almost equal to that of N (Sadanandan *et. al.*, 1998). In most plant species the K requirement in leaves, fruits and tubers is about 20-50 kg^{-1}g. Potassium, although not itself a constituent of any metabolite, plays a key role in functions of plant

Photos 1. Turmeric rhizome (BARI Holud-3) is a popular spice in Bangladesh. Photos by S. Akhter.

physiology and metabolism (Marschner, 2012). These functions relate directly to the beneficial effects of K on both crop yield and quality. Potassium activates numerous enzymes, is required in high concentrations for protein synthesis and is needed in both the light and dark reactions of photosynthesis. Additionally it plays a major role in osmoregulation and is thus directly involved in growth in cell extension. Its control of the turgor changes of guard cells in the stomata means that K regulates water loss from plants via transpiration. Potassium is highly mobile in plants and readily moves from older to younger leaves so that, like N deficiency, symptoms of K deficiency appear first in the older leaves. Potassium also increases resistance of plants against both biotic and abiotic stresses which is of high importance in crop production.

Spice crops like turmeric (*Curcuma longa*) and ginger are highly sensitive to a lack of K and require a large amount of available soil K which must be maintained because much of the K taken up by the roots is removed by the harvested crop. Crop response studies to K fertilization in different spice crops showed that among the three major nutrients, K is required in greatest amounts (Sadanandan *et al.*, 2002). Application of K has also been shown to increase yield, size of fingers in ginger and turmeric, oleoresin in ginger, and curcumin recovery in turmeric. Potassium also indirectly improves utilization of N and protein formation, in terms of size, weight, color etc. (Sadanandan *et al.*, 2002). In turmeric plants K deficiency manifests itself as chlorotic lesions and drying of leaf tips. Sadanandan (1993) reported that in black pepper (*Piper nigrum* L), K from older leaves is re-distributed to the younger growing tissues, resulting in deficiency symptoms in older leaves, leading to a drastic reduction in crop growth. The importance of K in plant nutrition and agricultural crop production has been well recognized and reviewed by many workers (Bidari and Hebsur, 2011). In general, adequate K nutrition has been shown to enhance yields and disease resistance of roots and tubers (Jansson, 1978). It also favors the establishment of root crops in the field (Rabindran and Nirmal, 2005).

Turmeric is a spice commonly used in cooking Asian food and is an excellent source of K. This rhizomatous spice crop which has been cultivated in Bangladesh since ancient times is one of the country`s major spices (Siddique and Azad, 2010). Turmeric is obtained by grinding the rhizomes to obtain the yellow colored powder curcumin. This powder is the main spice in Asian cuisines and curry powder. Most turmeric produced is used as a condiment but is also used as a coloring agent by food industries. A small quantity is taken by the cosmetics industry in Bangladesh. The medicinal value of turmeric is also well recognized in Bangladesh. Turmeric has a high demand for plant nutrients and generally responds to increased soil fertility by increasing yield. The quantity of fertilizers (inorganic or organic) required by the crop depend on the variety selected as well as the soil, and weather conditions prevailing during crop growth (Karthikeyan *et al.*, 2009). Among the spices, turmeric removes the most K (see Photo 2), followed by ginger and pepper (Sadanandan *et al.*, 2002).

Photo 2. Potassium fertilized turmeric crop. Photo by S. Akhter.

In Bangladesh, the recovery and diversification of spice exports to international markets is a real possibility but this may be restricted by a lack of K supply (Akhter *et al.*, 2013). Akhter *et al.* (2013) reported very good adaptation of spices in northern Bangladesh, although the sandy soils of this region are highly leached and the consequent lack of K can become a constraint to spice production. Spice crops like turmeric and ginger are highly sensitive to a lack of K and require a large amount of available soil K. In the case of turmeric in particular, there is a growing understanding by farmers of the importance of using K, balanced by the use of N and P fertilizers to improve rhizome yields. This has contributed greatly to the economic viability of the crop and led to an increase in demand for K fertilizers. There is, however, a need for a quantitative investigation as to how much K is required by turmeric and how efficiently this nutrient is utilized.

The field study reported in this paper on turmeric was carried out on a K deficient sandy soil in north Bangladesh to investigate the influence of increasing rates of K supply under conditions of adequate supply of all other nutrients. The aims of the experiment were as follows: (i) to establish the optimum application rate of K to obtain maximum yield and to consider the associated yield components; (ii) to determine the uptake of K by the crop; and (iii) to draw up a K balance sheet of K uptake and loss in this particular soil.

Materials and methods

The experiment was established at the Bangladesh Agricultural Research Institute's (BARI) Spices Research Center (SRC) experimental farms at Shibganj, Bogra (lat 24°51'0 N, long 89°22'0 E, 23 m elev.). The site is within agro-ecological zone (AEZ) 25 (terrace soil of the Level Barind Tract), which is flood free, highland with light-textured (sandy loam) K deficient and high-permeability soil. The variety of turmeric tested over two seasons (2010-2011 and 2011-2012) was BARI Holud-3. In both years, the unit plot size was 2 m x 1.5 m. There were five treatments comprising, viz. T_1=K_0, T_2=K_{40}, T_3=K_{80}, T_4=K_{120} and T_5=K_{160} kg ha^{-1} with three replications. The experiment was laid out in a Randomized Complete Block Design (RCBD). All treatments received a blanket dose application of $N_{133}P_{18}S_{13}Zn_2$ kg ha^{-1}. Urea, triple super phosphate, MOP, gypsum and zinc sulphate were used as the sources of N, P, K, S and zinc (Zn), respectively. This treatment provided a balanced nutrient supply to accompany the various rates of K supply. The total amounts of P, S and Zn were applied at the time of final land preparation. Nitrogen and K were applied as a top dressing in three equal splits at 80, 120 and 180 days after planting. Two rhizomes of turmeric were sown in May in both years in each pit and on emergence the plants were thinned to one plant per hill. Rhizomes were planted maintaining a spacing of 50 cm x 25 cm between and within the rows.

The seed rhizomes/fingers were planted at a depth of 8 cm. Weeding was done periodically whenever necessary. The crops were harvested when all the plants started drying in February 2011 and 2012. Data on various parameters including yield and K concentration of 10 randomly selected plants from each treatment were recorded. Collected data were analyzed statistically with the help of a statistical package, MSTAT-C, and Duncan's Multiple Range Test (DMRT) was used to determine the significant differences between treatments (Steel and Torrie, 1960). Plant samples were also collected from each plot for chemical analysis.

Soil chemical analysis

Prior to fertilizer application, initial soil samples in the study area were collected from 0-15 cm soil depth, and were analyzed for all important soil parameters using standard procedures (Table 1). The soil was found to be slightly acidic, intensively leached, and deficient in soil available K, as well as S and boron (B).

The following chemical determinations were made: pH by use of a combined glass calomel electrode (Jackson, 1958); organic carbon by the wet oxidation method (Walkley and Black, 1934); total N by a modified Kjeldahl method; calcium (Ca) and magnesium (Mg) by atomic absorption spectrophotometric (AAS); and K by flame photometry following soil extraction with NH_4OAc. Manganese (Mn) and Zn were also determined by AAS after DTPA (diethylenetriaminepentaacetic acid) soil extraction. Available P was estimated by the Bray and Kurtz method and B by the $CaCl_2$ extraction method. Sulphur was determined using the turbidimetric method with $BaCl_2$.

Plant chemical analysis

At harvest, the collected plant samples from each plot were dried at 65°C in an electric oven for 72 h, then ground to pass through a 20 mesh sieve and analyzed following standard procedures. Plant samples were digested with HNO_3-$HClO_4$ (3:1) for K determination using a flame photometer. Nutrient uptake was calculated by multiplying the concentration of K in the plant samples (see Photo 3) with the corresponding plant dry weights. Potassium balance was calculated by subtracting outputs (K removed or taken up by turmeric rhizome and straw) from the inputs (K added as fertilizer) (Panaullah *et al.*, 2000).

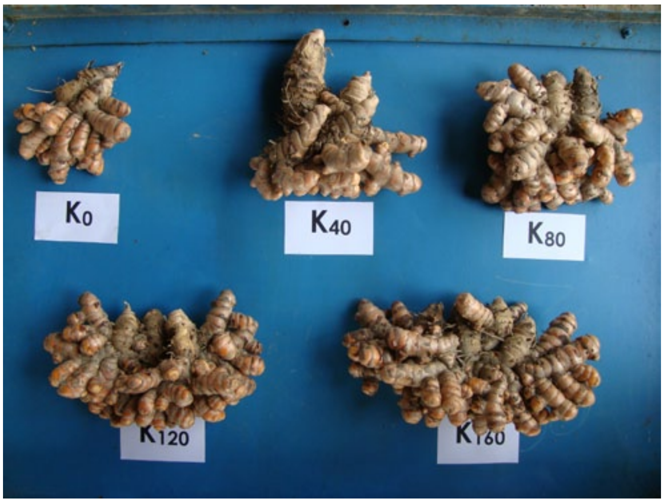

Photo 3. Effect of K on turmeric rhizome. Photo by S. Akhter.

Results and discussion

Yield and yield contributing factors

The results for yield and yield contributing characters of turmeric over two seasons (2010/11 and 2011/12) are presented in Table 2 and Fig. 1. Turmeric responded significantly to K fertilization in Terrace soil of the Level Barind Tract (AEZ 25) at Shibgonj, Bogra, in both years. The positive response of turmeric to increased K fertilization expressed itself through yield contributing characteristics much more in the 2011/12 season than the previous

Table 1. Fertility status of the soil at SRC.

Soil parameters	pH	OM	Ca	Mg	K	Total N	P	S	B	Mn	Zn
		%	-----*meq 100 g*$^{-1}$-----			%	----------------*μg g*$^{-1}$----------------				
2010-2011	5.6	0.98	4.2	0.8	0.11	0.08	14	9	0.17	8.3	1.30
2011-2012	6.1	1.20	4.6	1.8	0.11	0.09	18	20	0.25	9.7	0.65
Critical level	-	-	2.0	0.5	0.12	-	7	10	0.20	1.0	0.60

Table 2. Yield contributing characters of turmeric as influenced by different rates of K application (average of 10 plants).

Treatment	Plant height		Tillers/plant		Leaves/plant	
	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12
	------------*cm*------------		---------------------------*No.*---------------------------			
T_1 (K_0)	163.80	103.0 c	3.2 c	2.3 d	20.5 d	8.5 d
T_2 (K_{40})	171.80	112.1 b	3.4 bc	2.9 cd	22.0 cd	12.1 c
T_3 (K_{80})	173.93	114.4 b	3.6 ab	3.1 bc	22.4 bc	13.9 c
T_4 (K_{120})	163.80	122.2 a	3.7 ab	3.7 ab	23.8 ab	18.1 b
T_5 (K_{160})	165.40	124.7 a	3.9 a	4.1 a	24.9 a	21.4 a
CV (%)	5.8	3.2	5.2	11.9	3.9	8.9

Note: Figures in a column having same letter(s) do not differ significantly at 5% level by DMRT.
All treatments received a blanket dose application of $N_{133}P_{18}S_{13}Zn_2$ kg ha^{-1}.

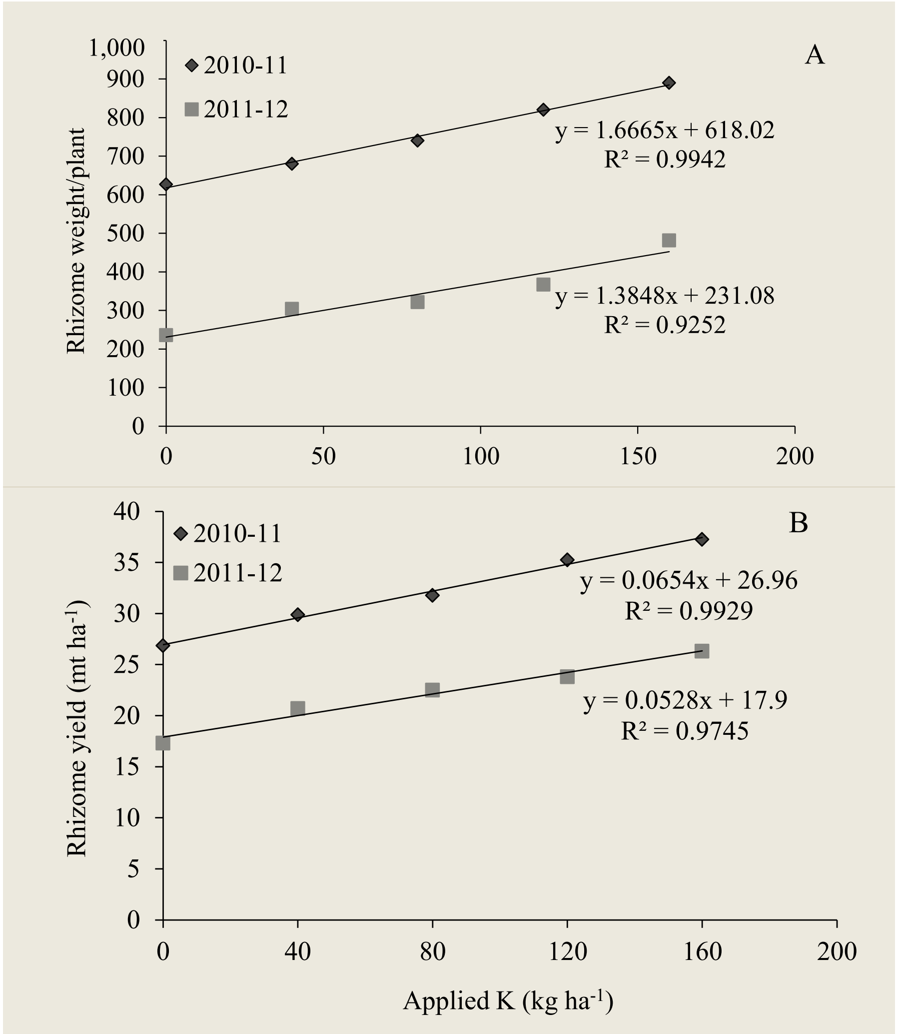

Fig. 1. Response of turmeric to K fertilization: (A) rhizome weight/plant and (B) rhizome yield in Bogra, 2010-11 and 2011-12.

one (Table 2). The weight of rhizome per plant (Fig. 1A) and rhizome yield (Fig. 1B) increased linearly (R^2>0.9) through the entire range of K application, from 0 to 160 kg K ha^{-1}, suggesting that additional K input may have further improved yield. In 2010/11, yield increased from 26.8 to 37.2 mt ha^{-1}, a 39 percent increase, while in 2011/12, yield increased from 17.3 to 26.3 mt ha^{-1}, a 52 percent increase (Fig. 1B). The increase in fresh rhizome yield might be attributed to the cumulative effect of all the yield contributing parameters of turmeric under study. Rathinavel (1983) reported significant increase in plant height, tiller production, number of leaves, number of mother, primary and secondary rhizomes and ultimately yield of turmeric due to K application. Singh *et al.* (1998) also showed that increasing rates of K application had a positive and significant effect on fresh rhizome yield. We explain the large difference in yield between 2010/11 and 2011/12 by heavy rainfall at the last stage of crop maturity. To conclude, during 2010/11 and 2011/12, application of 160 kg K ha^{-1} increased rhizome yields by 46 percent (as an average of the two years) over the control (K_0).

K uptake and balance

An apparent K balance was estimated on the basis of K supplied by fertilizer and removed by K uptake by the turmeric plants (Fig. 2). A well-defined pattern emerged in relation to K application. With increasing rate of K application, uptake of K increased and K balance also decreased correspondingly. Potassium uptake ranged from 68 to 180 kg K ha^{-1} as the rate of application increased. It is of interest that the K balance was found to be negative in all the treatments in the location under study, even though the crop had received balanced fertilization with other nutrients. The uptake of K by turmeric ranged between 68 to 180 kg K ha^{-1} for the varied rates of K application (Fig. 2). This finding is in agreement with the observation of Karthikeyan *et al.* (2009) and Sadanandan *et al.* (2002)

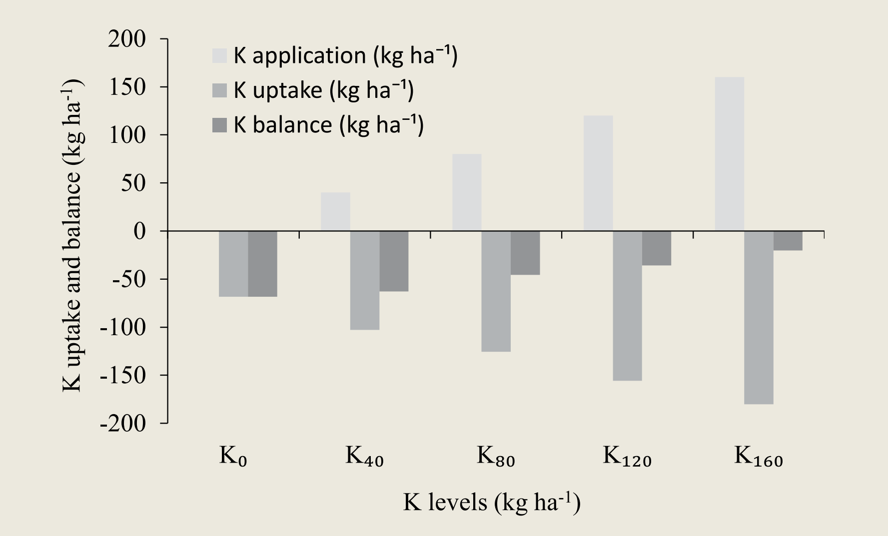

Fig. 2. Apparent K balance for turmeric in Bogra, 2010-2011.

who reported uptake of K to be highest, compared to other nutrients, by spice crops. These findings also reported an annual removal of 194 kg K ha^{-1} by turmeric through harvested produce which is in close agreement with our finding of 180 kg K ha^{-1} occurring at the highest rate of K application of 160 kg K ha^{-1}. Spice crops thus have a high demand for K which determines both yield and quality. This is especially important for turmeric which takes up large amounts of K from the soil which is removed at harvest in the rhizomes. Apart from this direct effect of K, the beneficial effect of K fertilization in increasing the uptake and utilization of other nutrients is an important aspect of K fertilization. Studies have also shown that K requirement of spices depends on the K status and dynamics in soil, the rooting pattern of different spices and varieties, and their productivity. There is thus an essential need for K to be supplied and maintained at optimum rates to augment production and improve quality (Sadanandan *et al.*, 2002; Sadanandan, 2000).

Economic performance

The economic performance of different levels of K is shown in Table 3. The highest gross additional returns in both years were with the highest K level applied. This resulted in additional income of approx. USD 2,200 to 2,600 per hectare, while the cost of K fertilizer applied was only USD 60 ha^{-1}. These findings also suggest that, with AE of over 50 kg kg^{-1} and relevant cost of input and harvested product, MOP application is not sensitive and should be applied sparingly.

Table 3. Economic performance of different levels of potassium on turmeric yield.

Treatment	Applied K	Agronomic efficiency K		Gross additional income		K cost
		2010/11	2011/12	2010/11	2011/12	
	kg ha^{-1}	-----------*kg kg^{-1}*-----------		----------*USD ha^{-1}*----------		*USD ha^{-1}*
T_1	0		-	-		-
T_2	40	76	85	755	850	15
T_3	80	62	65	1,233	1,300	30
T_4	120	70	54	2,100	1,625	45
T_5	160	65	56	2,600	2,250	60

Note: Input Price: kg K = Tk. 30; Output price: 1 kg turmeric = Tk. 20; 1 USD = 80 Tk.

Conclusion

The influence of K on growth, and yield parameters of turmeric (BARI Holud-3) was assessed through two field experiments on a Haplaquept light textured K deficient Terrace Soil of the Level Barind Tract (AEZ 25) in Bogra, the major turmeric growing region of Bangladesh. Turmeric was found to be highly responsive to K (AE achieved >50 kg kg^{-1}) which increased yields in the study area. Increasing the rate of application of K in the form of MOP enhanced growth, nutrient uptake and utilization, increasing yield of turmeric. Uptake of K by turmeric ranged between 68 and 180 kg K ha^{-1} and increased with increasing rate of K application. A negative K balance was observed even with balanced fertilization, implying the importance of K management in achieving sustainable yields and maintaining soil health. Economic analysis also showed very high profitability for potash application, exceeding USD 2,000 ha^{-1}.

Considering the economic returns, the linear response to K application and the negative K balance, the need for further investigation using higher levels of nutrient application should be considered. In the meantime, we strongly support that application of K at 160 kg ha^{-1}, along with a blanket dose of $N_{133}P_{18}S_{13}Zn_2$ kg ha^{-1}, be adopted as the best-suited dose for maximizing the yield of turmeric in K deficient Terrace Soil in the Level Barind Tract (AEZ 25).

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The paper "Response of Turmeric (*Curcuma longa*) to Potassium Fertilization on K Deficient Soil in Northern Bangladesh" also appears on the IPI website at:

Regional activities/East India Bangladesh & Sri Lanka

Research Findings

Photo 1. Typical vertisol that is used for cereal production (Ethiopia 2012). Photo by IPI.

Potassium Response in Vertisols in Long-Term Fertilizer Experiment in India

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Abstract

Ongoing long-term fertilizer experiments (LTFE) were carried out between 1972 and 2006 at 17 locations throughout India with the aim of monitoring the response of crops to nutrients in different soils and cropping systems in relation to the role of fertilization in sustaining soil health and crop productivity. Results generated over the years in the LTFE indicated that at five locations of vertisols or associated vertisol centres which were considered rich in potassium (K), crops began to show response to K fertilizer application. In order to assess the response of crops to the applied K, the data generated over the years has therefore been closely re-examined. At one of the locations in Jabalpur, a response to K was seen after a few years of experimentation in soybean-wheat and a gradual increase in magnitude of response to applied K has been observed with time. At another site in Akola, both sorghum and wheat showed response to applied K, which also increased with time despite the available K content of the soil being greater than that generally considered as high status. Analysis of soil K revealed that an absence of K in the fertilizer schedule resulted in a decline in K status from 2.1 to 9.7 kg ha^{-1} yr^{-1} and addition of nitrogen (N) and phosphorus (P) accelerated the mining of K. On the other hand, the decline in available K status was arrested by the addition of K (NPK and NPK+ farm yard manure; FYM), which in some cases led to an increase in available K. The relationship between available K status and Bray's percent yield

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Distribution of vertisols (marked in brown on the map). *Source:* Harmonized World Soil Database Viewer V1.21 3/2012 .

indicated ~330 kg K ha^{-1} as a threshold value for vertisols rather than the current recommendation in India of 280 kg ha^{-1}. This finding indicates that there is a need to modify or raise the critical limit for K rating of vertisols, otherwise a lack of K could pose a threat to sustainability.

Introduction

Potassium (K) is an essential plant nutrient playing an important role in various physiological and biochemical activities and is required in high amounts to maintain adequate crop growth (Mengel and Kirkby, 2001). The post Green Revolution era in India saw the use of imbalanced chemical fertilizer applications often high in nitrogen, the introduction of irrigation and the advent of high yielding varieties. The combined effect of these developments has been to accelerate the mining of K in soils resulting in inadequacy of available K in many soils. Currently the majority of Indian soils are in negative balance of K in terms of crop production. Rainfed crops are more prone than irrigated crops because, in contrast to irrigation water, rainwater does not allow any possibility of addition of K to the soil (Singh and Wanjari, 2012). Another important factor relating to the negative K balance is that in India, crop residues are not returned to the soil. Despite the fact that it contains a high proportion of K taken up by the crop, straw has multiple other competitive uses including for cattle feed and fuel. A response to K fertilization is thus to be expected.

An all India Coordinated Research Project on long-term fertilizer experiments (LTFE) has been in progress for many years at 17 locations across the country. It covers predominant cropping systems and soil types studying the response of crops to applied nutrients in terms of crop productivity and also monitoring nutrient status in the soil as well as the nutrient balance in the various soil crop systems. At several locations it is now well established that availability of K has become a yield limiting factor and a decline in yield because of 'hidden hunger of K' in very different soils of India was reported by Wanjari *et al.* (2004). Regular monitoring of the soil is essential to establish soil K status to avoid loss in productivity and in this respect these long-term fertilizer experiments have provided an excellent opportunity to study the impact of continuous fertilizer application on K-status and crop response under different cropping systems. Additionally, experiments have allowed the development of strategies for efficient utilization of K in sustaining productivity.

Of the 17 centres across India at which these LTFE are located, five of the locations are on vertisols or associated vertisols. These soils are considered to be high in available K as well as in reserve K because of the presence of K bearing minerals, including biotite and vermiculite, so application of K fertilizers has not generally been considered necessary. There is now much evidence, however, at least on some of these soils, that the rate of release of K is unable to meet the demands of the crop so that yields are impaired, especially when other nutrients are present in adequate amounts. For example, a negative balance of 56-163 kg K ha^{-1} yr^{-1} in an eight year old rice-wheat system was reported by Singh *et al.* (2002a). Similarly, in a soybean-wheat cropping system, an annual negative K balance of as high as 66-107 kg K ha^{-1} yr^{-1} was recorded by Singh *et al.* (2002b). Crop responses to K fertilization on a vertisol have also been found by Singh and Wanjari (2012), a finding in accord with the report of a long-term study in vertisols cited by Khan *et al.* (2014), indicating a sharp decline in available soil K as measured by ammonium acetate extraction.

This paper further investigates K balance in crop production and the response of different crops to K growing in vertisols using results emanating from the LTFE in India.

Experimental details

The five locations of the vertisols or associated vertisol centres from which data was collected were: Akola (sorghum-wheat), Jabalpur (soybean-wheat), Junagarh (groundnut-wheat), Raipur (rice-wheat) and Parbhani (soybean-safflower). Details of cropping system, soil type, and state and locations of LTFE are described in Table 1.

Amount of nutrients applied were based on recommended dose of each nutrients based on soil analysis. The methods used for determination of available nitrogen (N), phosphorus (P) and K were $KMnO_4$ oxidizable N, Olsen P, and ammonium acetate extractable K, respectively.

The 100% doses of N, P and K for each crop grown at different locations are given in Table 2. In one of the treatments, FYM was applied once a year during the rainy season, in addition to the 100% NPK. Each year, the amount of nutrient applied was the same in the particular experimental field for each of the respective treatments. During the rainy season (June to September) crops were sown with the onset of the monsoon but irrigated in the event of an early end to the monsoon or, in the case of a prolonged dry period, between two rain events. However, the second crop (November-April) was grown exclusively under irrigation. On all five selected sites in the study the soils were alkaline and non-saline and developed on basaltic parent material. The initial available N, P and K status of the soils is given in Table 3. The intercultural operations such as weeding, insect and pest control measures were followed as required. Crops were harvested at maturity and grain and straw samples were analyzed for K concentration to determine uptake and balance. Grain yields were reported at 11% moisture content in the grain.

Results and discussion

Soil nutrient status

Nitrogen

Soils on all the five sites selected were low in available N at the time of inception of the experiment (Table 2). Application of 100% NPK resulted in little increase in available status of N, possibly because of increase in soil organic carbon.

Phosphorus

Akola, Junagarh and Jabalpur soils were low in initial P-status (available P) (Table 2). Continuous use of 100% recommended dose of NPK enhanced this value at all the sites, whereas the value declined in the absence of P in the fertilizer schedule.

Potassium

Potassium status data revealed that absence of K supply resulted in a decline in available K in all five soils except at Parbhani. Application of K as per recommended dose maintained its status in Akola and Parbhani soils only, maybe because of a shorter period of the LTFE, while at the other locations decline in available K was recorded.

Table 1. Nutrient rates used under various cropping systems at different LTFE sites.

Location, soil type	Crop	Fertilizer rates at 100% NPK based on soil test			FYM added(1)
		N	P	K	
		-----------------	*kg ha^{-1}*	-----------------	*t ha^{-1}*
Madhya Pradesh; Jabalpur (1972), Typic Chromustert	Soybean	20	35	17	15
	Wheat	120	35	33	-
	Maize fodder(2)	40	30	17	-
Maharashtra; Akola (1986) Typic Haplustert	Sorghum	100	50	40	10
	Wheat	120	26	50	-
Gujarat; Junagarh (1996) Vertic Ustochrept	Groundnut	25	22	0	5
	Wheat	120	26	50	-
Chhattishgarh; Raipur (1996) Typic Haplustert	Rice	100	26	33	5
	Wheat	100	26	33	-
Maharastra; Parbhani (2006) Typic Haplustert	Soybean	30	26	25	10
	Safflower	60	18	0	-

(1)FYM=Farm yard manure; (2)Maize fodder discontinued in 1994

Source: Swarup and Wanjari, 2000; Singh and Wanjari, 2009.

Table 2. Initial and current status (0-15 cm) of available N, P and K (kg ha^{-1}) at different LTFE locations.

Location (year LTFE was initiated)	Available N			Available P			Available K		
	Initial	Control(1)	NPK	Initial	Control	NPK	Initial	Control	NPK
					kg ha^{-1}				
Madhya Pradesh; Jabalpur (1972)	193	192	263	7.6	9.0	29	370	175	266
Maharashtra; Akola (1986)	120	170	273	8.4	12	29	358	228	386
Gujarat; Junagarh (1996)	183	203	204	7.6	7.9	24	290	187	210
Chhattisgarh; Raipur (2006)	236	218	241	16.0	11.0	25	474	448	428
Maharashtra; Parbhani (2006)	216	194	223	16.0	15.7	18	766	745	792
Critical range(2)	N = 280-560			P_2O_5 = 11-25			K_2O = 121-280		

(1)Control means growing crop without fertilizer and manure; (2)Dhyan Singh *et al.*, 1999.

Note: Bulk density of surface soil (0-15 cm) was used to calculate nutrient status in kg ha^{-1} in each soil.

Source: Singh and Wanjari, 2009.

Table 3. Average crop yield (kg ha^{-1}) in vertisols at different locations of the All India Coordinated Research Project; AICRP-LTFE.

Location, state and place (years)	Crops	Control	N	NP	NPK	150% NPK	NPK+FYM	CD[(1)] (p=5%)
				---------------kg ha^{-1}---------------				
Madhya Pradesh, Jabalpur (41)	Soybean	829	1,036	1,656	1,829	1,849	2,025	150
	Wheat	1,264	1,691	4,104	4,495	4,808	4,932	284
Maharastra Akola (26)	Sorghum	282	1,981	2,701	3,382	4,243	4,291	354
	Wheat	143	932	1,323	2,006	2,495	2,568	241
Gujarat, Junagarh (16)	Groundnut	693	705	742	850	899	952	130
	Wheat	1,785	1,827	2,458	2,603	2,699	3,168	257
Chhattisgarh, Raipur (6)	Rice	2,381	3,722	5,065	5,128	5,610	5,474	356
	Wheat	1,056	1,536	2,272	2,278	2,622	2,497	287
Maharashtra, Parbhani (6)	Soybean	1,382	1,526	2,246	2,368	2,639	2,642	198
	Safflower	1,111	1,248	1,659	1,685	1,844	1,871	183

[(1)]CD = critical difference

Crop productivity

Yield data (since inception to 2013) clearly demonstrated that application of N and P resulted in increase in productivity irrespective of location (Table 3). Response to K application (NPK treatment), however, was recorded only at Jabalpur and Akola. Slight but non-significant increase in yield was recorded at Junagarh, Raipur and Parbhani. Crops did not show any response to applied K at Junagarh and Raipur even though Junagarh soils were low in K status. At Junagarh, irrigation water contains 6 parts per million (ppm) sodium (Na), which may be responsible for a lack of K response since a number of crops can utilize Na in place of K to a varying extent (Marschner 2012). However, at Raipur, soil K is sufficient to meet the K requirement of crops. But, at the rate at which availability of K is declining, K could become a limiting nutrient in the future (Table 6). The larger yields, with 150% NPK and NPK+FYM, at some of the locations were due to application of organic matter and larger amounts of nutrients.

Data on agronomic efficiency of K at the two responsive sites (Jabalpur and Akola) indicates that application of one kg K resulted in an increase of grain yield which ranged from 10.2-17.0 kg (Table 4). Crop response to the applied K depended on both the availability of K in the soil and productivity level. Continuous growing of crops without K application led to a decline in available K status from 370 to 223 kg K_2O ha^{-1} at Jabalpur, and at Akola available K status dropped from 358 to 255 kg K_2O in the NP treatment. These values are far below even the old threshold level of K so that K response is therefore to be expected and likely to increase in the future.

Potassium response

The response of the crops to K with time has been calculated and presented in Fig. 1A and 1B for Jabalpur and Akola, respectively. Review of the data presented in Fig. 1A indicates a gradual increase in K response with time since inception of the experiment at Jabalpur. In wheat the magnitude of K response was larger than that of soybean. At Akola, both sorghum and wheat showed response to K and a very high response has been seen in recent years (Fig. 1b). This appears to be due to a decline in available K status particularly in the NP treatment. Although slight improvement in yields on application of K at other locations was also recorded, this was not statistically significant. In spite of high estimates of K, the response of crop to applied K could be due to increase in estimates of K availability on drying soil. In fact, in actual moist conditions, K status is probably less than required as reported by Khan *et al.* (2014). Reviewing the results of a large number of studies carried out in many countries revealed that, on drying, ammonium acetate extractable K in soil increases tremendously (~2 to 3 fold) compared to moist soil. This could be a possible reason for crop response to applied K because the available K status is very low in moist soil whereas fertilizer recommendations are made on the basis of K estimates analyzed in dry soil.

Potassium balance in Jabalpur

On the basis of K input (fertilizers added) and output (removal in harvested crop parts) an apparent balance was calculated on the soybean-wheat system at Jabalpur (Table 5) which showed a negative K balance of 72-206 kg K ha^{-1} yr^{-1}. This negative balance, in spite of K application, can be accounted for by the larger K uptake than that applied and this is probably responsible

Table 4. Agronomic efficiency (kg grain/kg K) of applied K in Jabalpur and Akola.

Location (years)	Crop	K application	Yield increase	Agronomic efficiency for K (AE_K)
		kg K ha^{-1}	*kg ha^{-1}*	*kg kg^{-1}*
Jabalpur (41)	Soybean	17	173	10.2
	Wheat	33	391	11.8
Akola (26)	Sorghum	40	681	17.0
	Wheat	50	683	13.7

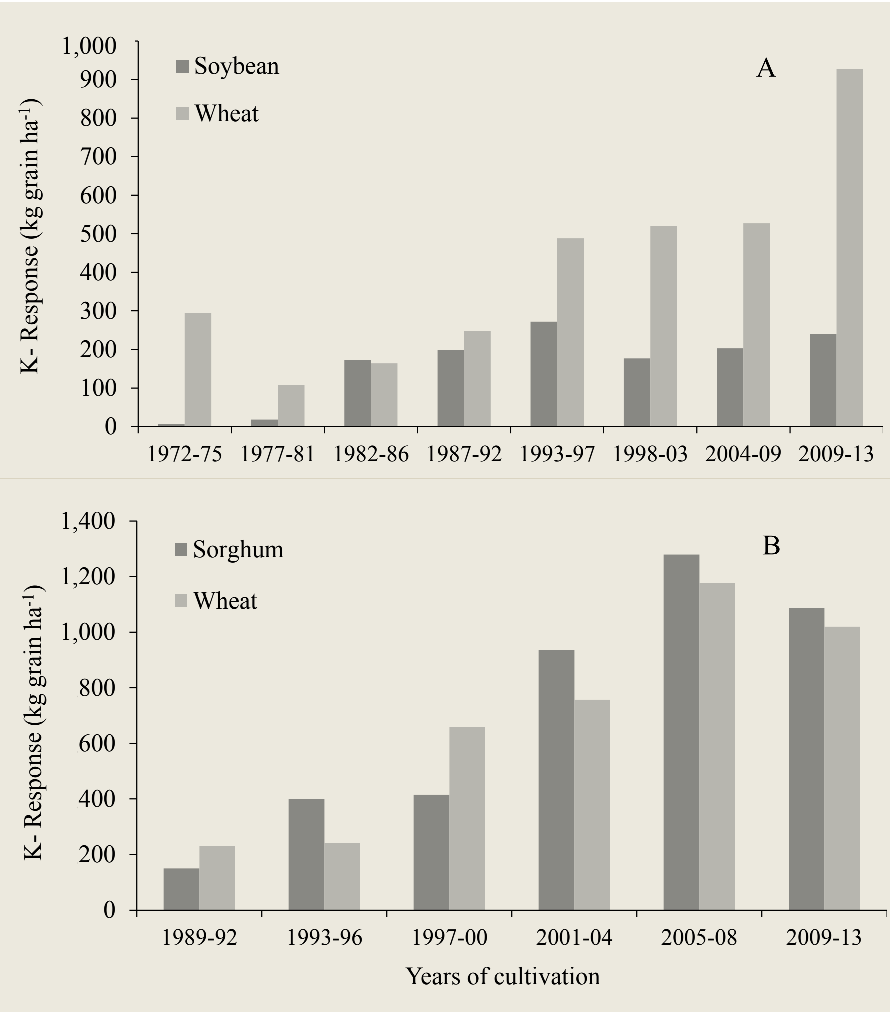

Fig. 1. (A)Soybean and wheat response to K in vertisols at Jabalpur (MP, India) with time; (B) Sorghum and wheat response to K in vertisols at Akola (Maharashtra, India) with time.

Table 5. Scenario of K balance (after 40 years) in soybean-wheat system at Jabalpur (MP, India).

Treatments	Total K added	Total K uptake	Apparent K balance	Apparent K balance
	---------------*kg K ha^{-1}*------------------		--------------*K kg ha^{-1} yr^{-1}*-------------	
Control	0	2,889	-2,889	-72
100% N	0	3,924	-3,924	-98
100% NP	0	8,668	-8,668	-217
100% NPK	2,374	9,760	-7,386	-189
150% NPK	3,374	11,633	-8,259	-206
100% NPK + FYM	6,294(1)	13,676	-6,552	-184

(1)Includes K added through FYM (K=0.65%).

for the crop response to applied K. In agreement with these findings a negative K balance of 66-107 kg ha^{-1} yr^{-1} in soybean system grown for eight years on vertisols of Bhopal was reported by Singh *et al*. (2002b).

Rate of decline in available K

Soil samples (0-15 cm) collected after completion of each cropping cycle were analyzed for available K. Table 6 illustrates the average annual rate of change (negative or positive) of available K in the soil. Irrespective of treatments, change in available K status in the control treatment was negative at all the sites. Moreover, in all locations, except Parbhani, the data further revealed that application of N and NP in the absence of K resulted in a decline in K at a higher rate compared to the control and the treatment receiving K. In Jabalpur and Raipur, K removal was so large that, even at the highest levels of added K, a depletion in K occurred. Yet, in Akola and Junagarh, the application of K minimized the negative K balance, and at high K application even caused an increase in available K in soil.

Critical limit of K in vertisols

To determine the critical limits of available K status for Jabalpur and Akola vertisols, K response trials were conducted on farmers' fields varying in available K status. The grain yield, termed Bray's yield, was noted at the point where an increase in soil K did not result in an increase in yield. Relative yields were calculated against this value for all field trials. The relative Bray's yields were then plotted against soil K status (Fig. 2). These experiments indicated a value of ~330 kg K_2O ha^{-1} (154 ppm K) as a critical limit which is greater than the 280 kg K_2O (132 ppm K) that is currently being used for K recommendation in India. This study clearly demonstrates that there is an urgent need to revise the threshold value of K for vertisols.

Conclusions

From the present study on vertisols at five LFTE sites, it can be concluded that there is evidence on some of these soils of a continuous decline in available K status in the absence of K in fertilizer application. After a few years without K supply crops began to show response to applied K. From experiments on these soils the threshold value for recommending K application was shown to be ~330 kg K_2O ha^{-1} rather than the

Table 6. Change in soil available K at different LTFE locations (kg ha^{-1} yr^{-1}).

Location (years)	Control	N	NP	NPK	150% NPK	NPK+ FYM
		-----------------------------	----*kg ha^{-1} yr^{-1}*----	-----------------------------		
Jabalpur (41)	-2.3	-2.1	-3.6	-2.7	-1.9	-1.4
Akola (26)	-1.7	-5.0	-4.2	+0.9	+2.6	+3.4
Junagarh (16)	-5.8	-6.8	-6.2	-4.5	-2.4	+1.0
Raipur (6)	-3.3	-6.8	-9.7	-5.0	-1.3	-3.1
Parbhani (6)	-3.5	NC(1)	NC	+4.3	+7.3	+9.1

(1)NC = no change.

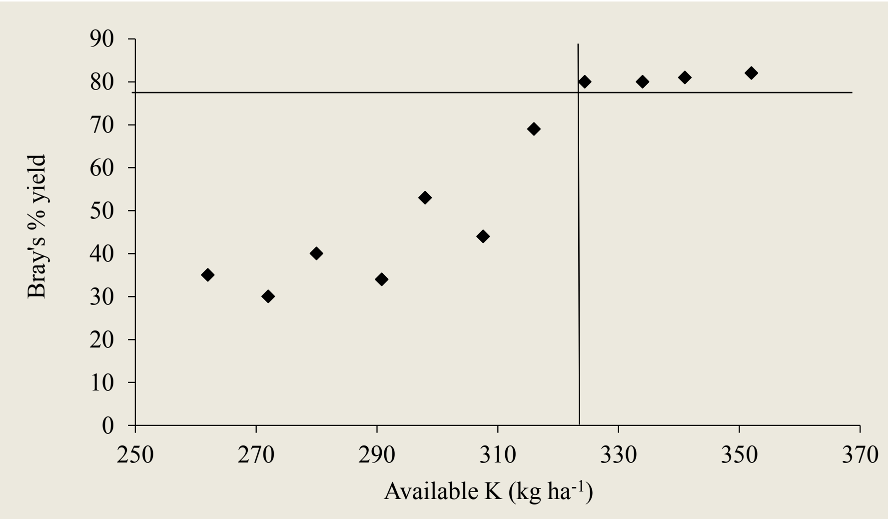

Fig. 2. Potassium response in Jabalpur and Akola vertisols (MP and Maharashtra, India).

lower 280 kg K_2O ha^{-1} which is currently being used in India. There is thus a need to conduct further response studies in the field to assess the threshold level of K for vertisols.

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The paper "Potassium Response in Vertisols in Long-Term Fertilizer Experiment in India" also appears on the IPI website at:

Regional activities/India

Research Findings

Wheat harvesting in Pakistan. Photo by A. Wakeel.

Critical Review of Research on Soil K and Crops' Response to K Fertilizers in Pakistan: Perspectives and Opportunities

Wakeel, A.[1]

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). As such, a clear NP fertilizer response has been observed in most Pakistani soils. High potassium (K) content is apparent in Pakistani soils developed from mica minerals, but the occurrence of soil K in large amounts does not represent plant-available K for optimum plant growth. In such soils, K is bound within minerals which do not release K at the rate required for crop production. On the other hand, some soils with low plant available K maintain levels of solution K that are optimal for plant growth, leading to no response to K fertilization. Release and fixation of K depends on the type and content of soil minerals, whose distribution and retention properties are therefore needed to develop K fertilizer recommendations for sustainable nutrient management. Soil mineral composition and K chemistry differ with development age and source of soil parent material. Use of K fertilizers in Pakistan is still under debate, due to diverse crop responses to K fertilizer. General K fertilizer recommendations,

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which are based on exchangeable K content in the soil and which ignore the soil mineralogy and K dynamics, may lead to non-responsive K applications. Nevertheless, K deficiency has been observed in many crops in different areas of the country. Recently, farmers have shown interest in K fertilization, as their expertise and technologies have improved. Being a key macronutrient for plant growth and yield development, K is taken up in higher amounts by all crops. Application of K fertilizers is therefore vital for sustainable agriculture in Pakistan and it is therefore the time for comprehensive studies to endorse K fertilization by presenting a clearer picture of crop response to K application. Soil mineralogy and K dynamics-based recommendations may be an effective tool to fill a wide crop yield gap in a country where the population is increasing at the rate of ~2.0% per year. Application of K fertilizers to extensively used soils is critical for sustainable agriculture, and K fertilization can be emphasized, specifically for certain soils, based on mineralogy and K dynamics.

Introduction

Potassium (K) is the most abundant macronutrient in most Pakistani soils. It is crucial for three important functions: enzyme activation, charge balance and osmotic regulation in higher plants. But the presence of a huge amount of K in the soil does not fulfill plants' requirements because a large amount of K is fixed by clay minerals present in these soils and it is not available to achieve optimum plant growth. Inadequate K fertilization is among the factors responsible for crop yield gaps in many parts of the world (Mengel, 2007), especially in developing countries. Furthermore, K dynamics in the soil based on type and age of clay minerals play an important role in the K nutrition of crops. A huge amount of K fertilizer is required for optimum crop growth, but plants do not respond sufficiently to normal K fertilization recommendations in soils containing K-fixing clay minerals. In a sandy clay loam soil of Michigan, about 92% of the applied K fertilizer was fixed and 1,600 kg K ha^{-1} was applied to make it responsive in tomato production (Doll and Lucas, 1973). This soil was rich in illite and vermiculite clay minerals with high cation exchange capacity (CEC); as a result, a major part of applied K was fixed and immediately became unavailable to the plants. Similar results have been obtained in other parts of the United States (Mengel and Kirkby, 2001). Recently, it has been reported that the presence of specific clay minerals affect the K-fixing capacity and slow and fast release of K in three different soils (Wakeel *et al*., 2013). Smectite-dominant soils have shown faster release of K than illite soils, and sugar beet plants did not respond to K fertilization in such soils. Potassium sorption on exchange sites and its fixation depend on the physicochemical properties of the soil, as well as the type and content of the clay minerals (Braunschweigh, 1980).

The major natural source of soil K is the weathering of K-containing minerals such as micas and alkali feldspars, which contain 6-9 and 3.5-12% K, respectively. The age of soil developed from such minerals determines the extent of weathering as well as the K dynamics. While taking up K, plants reduce its concentration in the immediate vicinity of roots, which releases K-ions from the minerals (Kuchenbuch and Jungk, 1984). 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). The fate of K fertilizer also depends on the age of the soil; application of K fertilizer to soils containing illite and vermiculite clay minerals leads to fixation of some of its fraction by soil particles. This fraction then becomes unavailable or slowly available to the plants (Scott and Smith, 1987). The fixed K may

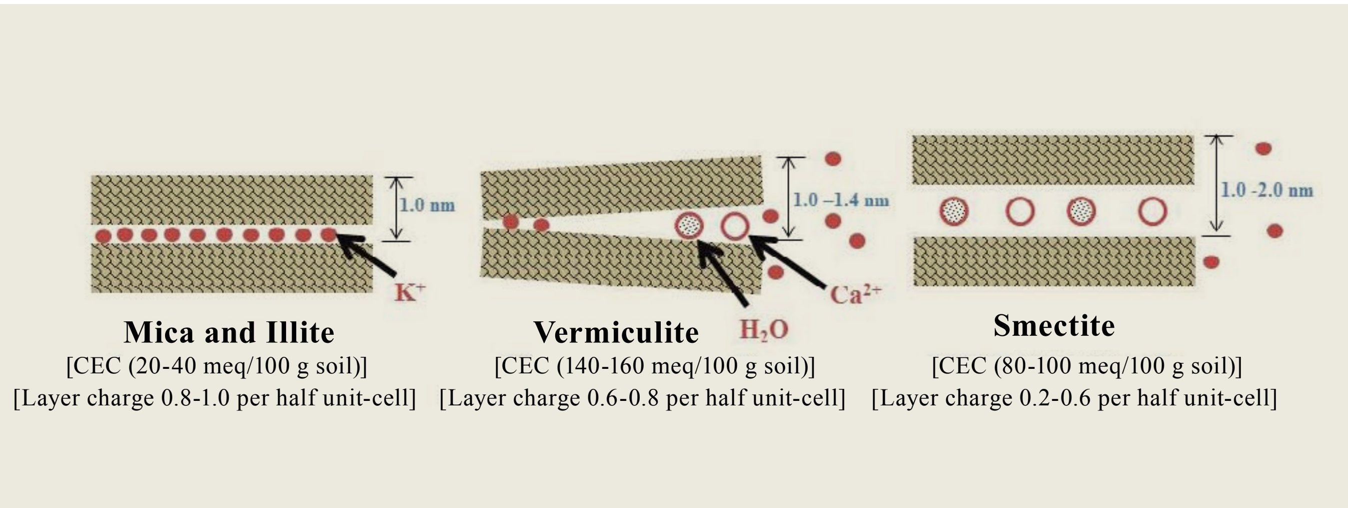

Fig. 1. Properties of four types of clay minerals often present in agricultural soils. Adapted from Wakeel *et al*., 2013.

become available to plants by its release from soil particles into soil solution when the concentration of K in the soil falls (Cox *et al*., 1999), but in most cases this release is too slow to meet the plant-growth requirements.

Potassium research in Pakistan

As Pakistani soils are developed from mica, a rich source of K, and most parts of the country are under canal irrigation systems, it was generally considered that soils of Pakistan could supply sufficient K for plant growth. However, considerable work has been done on K fertilization, and its response in many crops has been observed for decades (Rehman *et al*., 1982, 1983; Gurmani *et al*., 1986; Khattak and Bhatti, 1986; Ranjha, 1995; Mian *et al*., 1998; Akhtar *et al*., 2002; Tariq *et al*., 2011), and considered as an established, well known reality in the scientific community. It has also been reported that in many soils, application of K fertilizer has not led to increases in yield, despite high apparent crop potential (Bajwa, 1985). This might be a factor in the failure of K fertilizer promotion in Pakistan.

Fixation of K by expanding type clay minerals has been considered as one of the reasons for reduced crop response to K fertilization. Khattak (2002) reported that the presence of high soil clay content and the type of clay minerals are responsible for fixation of added K and recovery of non-exchangeable K already present in the soil. Soils differing in clay mineralogy may respond differently to K fertilizer application (Akhtar and Dixon, 2013). It was further explained that Laylpur soils may not require K addition for optimum plant growth due to the presence of smectite clay minerals. Awan *et al.* (1998a) reported that K fixation does not have direct correlation with total clay content but with the types of clay mineral dominant in the soil. Clay content and the weathering stage of parent material have a strong relationship with extractable K (Awan *et al*., 1998b). Application of potash to maize in sandy clay loam and sandy loam have shown clear growth increases in maize, whereas in clay loam soils, application of K fertilizer did not produce a response, perhaps due to either K-fixation or there already being enough K in the soil (Wakeel *et al*., 2002).

Working on soils at an early profile development stage, no long-term fertilizer treatment effect on K-fixation in the soil was observed. However, marginal changes in soil bio-available K and in the mineral composition were observed, due to less K fertilization in the canal irrigated cotton-wheat system (Sheikh *et al*., 2007). While reviewing studies in K fertilization, Bhatti (2011) concluded very critically that future perspectives for promotion of K fertilization lie in recommendations based on K-fixing capacity and clay mineralogical composition of agricultural soils. Clay mineralogy is strongly related with the profile development and weathering stage of the soils, so the soil weathering stage may have a significant role in determining K availability.

Use of potash fertilizers

After the green revolution of the 1960s, chemical fertilizer use was promoted in Pakistan, as in many other parts of the world. Beginning with the use of nitrogenous fertilizer, phosphatic (P) fertilizer was introduced later in the 1970s, with amounts increasing over time. Nitrogenous fertilizer use was significantly higher, however, due to better, quicker and more cost-effective crop responses at that time. Wheat is the most fertilized crop in Pakistan, with cotton in second place; other crops have not been fertilized to a great extent. As can be seen in Fig. 2, a slow and steady increase in P fertilizer usage continued, up until the last few years. Despite this, however, application rates for potash have been discouragingly low in all the crops, with the exception of

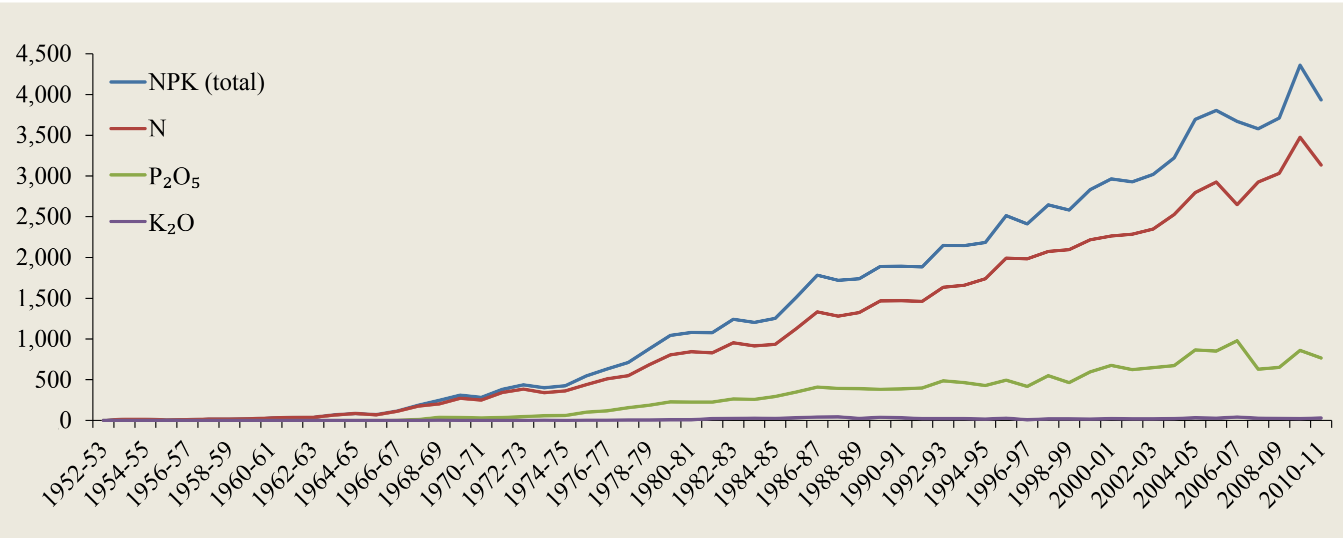

Fig. 2. Chemical fertilizer use (N, P and K) in Pakistan from 1952-2011. *Source:* Economics Survey of Pakistan, 2012-13.

Wheat harvesting in Pakistan. Photo by A. Wakeel.

Manual wheat harvesting in Pakistan. Photo by A. Wakeel.

potatoes, where farmers are using potash fertilizers for better yields as well as improved tuber quality.

A number of efforts have been made by the government, as well as national and international organizations, but the use of potash has remained miserably low. Average use of potash fertilizers per hectare is less than 2 kg, compared to 132 kg for N and 32 kg for P fertilizers, which is very alarming. Imbalanced fertilization is always uneconomical and discouraging for farmers, with the very low ratio compared to K and N fertilization causing a number of problems, such as lodging in crops grown in certain areas. Introduction of compound fertilizers such as NPK has added some potash to the fields, but this has reduced the presence of K_2SO_4 (sulfate of potash; SOP) fertilizer in the market, such that SOP is now very rare in the country. Over the last few years, a number of liquid fertilizers have been introduced in the market by various private companies. These fertilizers are recommended as fertigation or as foliar application, but are not yet widely adopted by farmers. However, we would suggest that application of K in such small amounts will not fulfill plant growth requirements.

A recent and more positive development has been the import of KCl (muriate of potash; MOP) instead of SOP by national fertilizer companies, which may boost the use of potash fertilizer in Pakistan. The cost of MOP in Pakistan is ~2/3 of SOP and may be more acceptable to farmers due to its low price. However efforts should be made to analyze the consequences, if any, of the use of chloride (Cl) in Pakistani conditions.

Causes of low potassium fertilization

Most Pakistani soils are mica based; due to continuous weathering, intensive cropping and K release, these soils generally convert to illite and vermiculite-dominant clay minerals. High yielding crop varieties mine the soil for K, normally without being replenished by use of K fertilizers. It is generally believed that due to a lack of resources, poor Pakistani farmers with small land holdings are not able to use potash as an agricultural input. However, the reality may be different, since these same farmers are using N and P fertilizers, and even very expensive pesticides. Lack of financial resources may contribute partially to low K fertilizer use in Pakistan, but there are other reasons, which can be categorized as follows:

Lack of awareness and misconceptions

Most farmers in Pakistan are poorly educated and not aware of the importance of balanced fertilization for crops. Secondly, a misconception among farmers also prevails that potash is not required where canal water is applied. Although canal water is a good contributor of K to irrigated fields, this is not enough to fulfill the requirements of high yielding crops. Previously, when soils were not as mined as they are now and crops were low yielding, this rationale may have been accurate. But due to population pressure, high yielding varieties have been introduced and, due to climatic changes and silting of water reservoirs, canal water is no longer sufficient and has therefore been supplemented by underground water.

Fertilizer recommendations

Generally, fertilizer recommendations are given by the provincial agriculture department, based on the general trend of fertilizer requirements in the province. Site-specific fertilizer recommendations are very rare in Pakistan. At district level, some soil fertility laboratories have been established by provincial governments but these may not be enough to meet the requirements of farmers. For N and P fertilizers, general recommendations may be satisfactory, but for K, these recommendations do not lead to a good crop response due to variations in soil mineralogy and K dynamics. As a result, farmers conclude that potash fertilization is not needed, and it is difficult to convince them otherwise when they are not getting any benefit in response to their expenditure on fertilizer. Comprehensive strategies are therefore required to create awareness and convince farmers.

Government policies and availability of K fertilizers

A number of research articles have been published by researchers working in Pakistan indicating the importance of potash fertilization, which show a clear response to potash in terms of crop yield and quality in different research trials. However, no solid action has yet been taken by the government to promote research on the importance of potash for agriculture. Fertilizer companies have also been unclear on the issue, and this is the reason that provision of K fertilizers in the country is very rare.

Future research perspectives

Instead of being recognized for its great importance for precise and sustainable agriculture, potash is continuing to be ignored. A solid research and awareness plan is therefore urgently needed to promote potash in Pakistani agriculture. In terms of future research, two aspects should be given immediate and careful consideration.

Precise potash recommendations

Precise fertilizer recommendations based on soil mineralogy and K dynamics are required to improve the crop yield and cost-effective use of K fertilizer. Initially, one district with a variety of agricultural crops should be selected. A certain number of soil series should then be selected based on already available information, soil sampling should then be done to investigate the soil mineralogy and K dynamics and recommendations should be compared with conventional potash recommendations based on exchangeable K in the soil. This will provide a cost-effective potash recommendation for maximum crop production and yield development.

Considering crop quality

It is well documented that adequate K fertilization improves the quality of cereals, cotton and other crops such as potato and sugar. Application to sugar cane and sugar beet increases the sucrose content in the produce, increasing sugar yield and production. Industries, especially the sugar industry, have to be taken on board in such studies; sucrose content-based sugarcane purchasing could also be introduced.

Conclusion

From previous research work, it is generally concluded that potash is required for most crops grown in Pakistan. However, for precise and more crop-responsive K application, potash recommendations based on soil mineralogy and K dynamics should be developed. As MOP has been introduced in the market, comparative studies of MOP and SOP should be conducted to investigate the Cl dynamics in the system. Public sector research institutions, fertilizer companies and agriculture-based industry should sit together to develop a research and awareness strategy for promotion of potash in Pakistani agriculture.

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The paper "Critical Review of Research on Soil K and Crops' Response to K Fertilizers in Pakistan: Perspectives and Opportunities" also appears on the IPI website at:

Regional activities/WANA

Events

IPI Events

March 2014

IPI-BAU International Symposium on "Potassium Nutrition and Crop Quality", BAU, Ranchi, Jharkhand, India, 4-5 March 2014.

Report by Neeraj Kumar Awasthi, IPI Coordinator East India, Bangladesh and Sri Lanka.

Over 150 scientists, extension specialists and agricultural administrators from all over the world participated in the International Symposium on 'Potassium Nutrition & Crop Quality'. Organised by India's Birsa Agricultural University (BAU) in collaboration with the International Potash Institute (IPI) on 4-5 March 2014, 131 research papers were presented during 10 sessions.

Photo 1 (top): The symposium opening. **Photo 2** (below): Welcome of chief guest Sri Yogendra Saw Ji., Minister of Agriculture, Jharkhand, by Dr. M.P. Panday, VC, BAU. Photos by N.K. Awasthi.

Neeraj Kumar Awasthi, IPI Coordinator East India, Bangladesh and Sri Lanka , highlighted the achievements of an IPI-BAU research project which demonstrated how balanced nutrition, in particular potassium, adds tremendous value to the socio-economic status of small and marginal farmers.

BAU Vice Chancellor, Dr. M.P. Panday, then drew the attention of participants towards the historical importance of chemical fertilizers and the important role they have played in making the country self-reliant in food grain production, especially during the Green Revolution (1960-70) when the country experienced an increase of over 50-60% in food grain production with the use of fertilizers.

Hillel Magen, IPI Director, raised concern about global food demand and how it should be addressed with the balanced use of fertilizers. Magen explained how IPI is partnering with research and extension agencies in the developing world to provide solutions to the increasing global demand for food.

Jharkhand state's Minister of Agriculture, Sri Yogendra Saw, congratulated the organisers of the Symposium for their effort to expose scientists, extension workers and farmers to global research. He highlighted the importance of generating and disseminating modern agricultural knowledge to increase the productivity and profitability of farmers. Saw promised that in Jharkhand, the government is working to facilitate agriculture as an industry.

The two day Symposium ended with a session, Chaired by India's Commissioner of Agriculture, Dr. J.S. Sandhu, in which a set of recommendations was compiled.

Symposium recommendations:

1. Promoting the balanced use of nutrients in a cost effective manner is indispensable for sustaining a high level of crop productivity.
2. Technology generated on nutrient use should match with farmer's perspectives. Last mile delivery to small and marginal farmers should be the focus. Reaching farmers through extension officers, NGOs and other agencies, using decision support systems, holds promise.
3. Farmer field trials and demonstrations, on use of potassium fertilisers, need to be conducted to encourage potassium use and create awareness among farming communities.
4. Re-looking at the threshold values of available potassium in soils and nutrient ratios in crops has become essential to tackling global food insecurity and market competitiveness.
5. Employing nutrient stewardship programs (e.g. 4R), potassium applied through complex and straight fertilizers in farmers' fields in different agro-climatic regions should be tested for higher farm profits.
6. Farmer field studies on potassium-use in crops and cropping systems under micro-irrigation, especially for high value crops, need to be monitored for yield, quality and tolerance to biotic and abiotic stresses. Laboratories equipped with improved tools for assessing quality parameters need to be set up.
7. Impact studies of non-application of potassic fertilizers (in nitrogen and phosphorus treated fields) for short, medium and long-term effect in farmer's fields on crop yield and quality is essential.
8. Potassium-use efficiency in commercial crops with export potential such as tobacco, cotton, spices, vegetables, fruits, and flowers need further study.
9. Efforts are needed to popularise the use of potassic fertilizers among farmers by reducing costs, improving supply and providing subsidies.
10. Split application/deferred application (e.g. potassium-fixing soils) of potassium in crops and cropping systems needs further research to determine the potassium-use rates needed by different crops to achieve high potassium-use efficiency.
11. Rain fed areas, pulses and oilseed crops need special focus on potassium-use to mitigate abiotic stresses. Screening of crop cultivars with higher potassium-use efficiency and promoting large scale use by farmers will help.

September 2014

1st IPI-Ministry of Agriculture-Agricultural Transformation Agency Ethiopia joint symposium in East Africa on "The Role of Potassium in Cropping Systems of sub-Saharan Africa: Current Status and Potential for Increasing Productivity", Addis Ababa, Ethiopia, 4-5 September 2014.

This event will be of interest to soil and plant nutritionists, agronomists, extension officers, as well as governmental/non-governmental organizations and private companies that have an interest in balanced fertilization. Invited speakers will include scientists from the region, and beyond. Poster presentations are open to all, and students are encouraged to participate and present relevant research related to the themes of the symposium.

Themes:

- Potassium Fertilizer Management in Major Cropping Systems of sub-Saharan Africa
- Current Advances made in the Determination of Potassium Status in Soils and Plants
- Evaluation of Soil Potassium Fertility in Ethiopia and East Africa
- Evidence of the Effect of Potassium Fertilization on Nutrient and Water Use Efficiency
- The Beneficial Role of Potassium in Tackling Biotic and Abiotic Stresses in Cropping Systems
- Nutrient Mining and Stagnation of Agricultural Productivity in sub-Saharan Africa
- Potash Production in Ethiopia: Prospects and Challenges
- Public-Private Partnerships: The Role of NGOs in Scientific Information Generation and Transfer

Confirmed Speakers:

- Sileshi Getahun, State Minister of Agriculture, Ethiopia
- Tekalign Mamo, Ministry of Agriculture
- Sam Gameda, IFPRI Ethiopia
- Oumou Camara, IFDC Ethiopia
- Teshome Lakew, Ethiopian Ministry of Agriculture
- Selamyihun Kidanu, Agricultural Transformation Agency, Ethiopia
- Benayahu Bar-Yosef, Agricultural Research Organization of Israel
- Erik Karltun, Agricultural Transformation Agency

- Bernard Vanlauwe, International Institute of Tropical Agriculture; IITA
- S. K. Bansal, Potash Research Institute of India
- Wassie Haile, Hawassa University, Ethiopia
- Hillette Hailu, Haramaya University, Ethiopia
- Abebe Shiferaw, Agricultural Transformation Agency
- Mulugeta Demiss and Taye Bekele, Agricultural Transformation Agency
- John Wendt, IFDC, East & Southern Africa Division
- Uri Yermiyahu, Agricultural Research Organization of Israel
- Bashir Jama, Director of Soil Health Program, AGRA
- Eyasu Elias, CASCAPE, Ethiopia
- Gezahegn Ayele, USAID/CIAFS, Ethiopia
- Nega Wubeneh, Ethiopian Agricultural Transformation Agency
- Hillel Magen, IPI

For more details contact Mr. Eldad Sokolowski, IPI Coordinator sub-Saharan Africa or see updates and information on the IPI website/Events.

International Symposia and Conferences

August 2014

29th International Horticulture Congress, Brisbane, Australia, 17-22 August 2014. See more details on the congress website.

September 2014

2014 African Green Revolution Forum, Addis Ababa, Ethiopia, 2-4 September 2014. For details go to the forum website.

October 2014

16th World Fertilizer Congress of CIEC, 20-24 October 2014, Rio de Janeiro-RJ, Brazil. See more details on the congress website.

4th International Rice Congress (IRC2014), 27 October - 1 November 2014, Bangkok International Trade and Exhibition Centre (BITEC), Bangkok, Thailand. See more details on the IRC2014 website.

January 2015

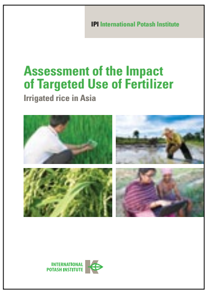
14th ISSPA International Symposium for Soil and Plant Analysis, 26-30 January 2015, Kona Beach, Hawaii. See more on the ISSPA 2015 website.

Publications

IPI Publications

Assessment of the Impact of Targeted Use of Fertilizer

Irrigated rice in Asia



In 2010, rice (*Oryza sativa* L.) was grown on 162 million ha, with 91% produced in Asia. It is the main staple food crop in Asia, providing more than 50% of calories in some countries. Worldwide, about 93 million ha of irrigated lowland rice (57% of the rice production area) provides 75% of global rice production. In Asia, rice is grown on 30-83% of all irrigated land.

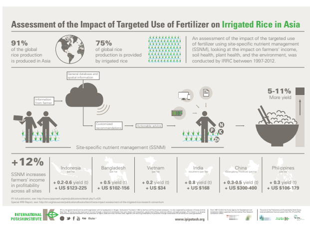
Rice provides 19% of global human per capita energy and 13% of per capita protein. But to provide for the future needs of the growing world population, rice production needs to grow annually by 1.2-1.5% over the coming decade (GRISP, 2013).

This publication provides an assessment of the impact of the targeted use of fertilizer using Site Specific Nutrient Management (SSNM), looking at the impact on farmers' income, soil health, plant health, and the environment.

The publication can be downloaded from the IPI website: http://www.ipipotash.org/publications/detail.php?i=425.

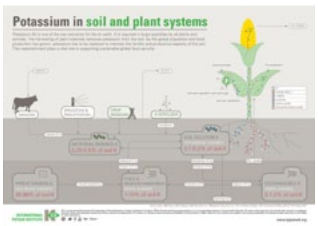
In addition, IPI has developed four infographics dedicated to the following subjects:

Assessment of the Impact of Targeted Use of Fertilizer on Irrigated Rice in Asia



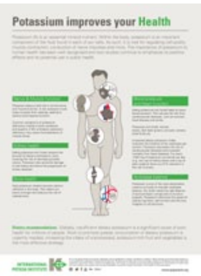
An assessment of the impact of the targeted use of fertilizer using site-specific nutrient management (SSNM), looking at the impact on farmers' income, soil health, plant health, and the environment, was conducted by IRRC between 1997-2012.

Potassium in Soil and Plant Systems



Potassium is one of the key elements for life on earth. It is required in large quantities by all plants and animals. The harvesting of plant materials removes potassium from the soil. As the global population and food production grows, potassium has to be replaced to maintain the fertility and productive capacity of soil. This replenishment plays a vital role in supporting sustainable global food security.

Potassium Improves Your Health



Potassium is an essential mineral nutrient. Within the body, potassium is an important component of the fluid found in each of our cells. As such, it is vital for regulating cell acidity, muscle contraction, conduction of nerve impulses, and more. The importance of potassium to human health has been well recognized and new studies continue to emphasize its positive effects and its potential use in public health.

Potassium Improves Your Crop Quality

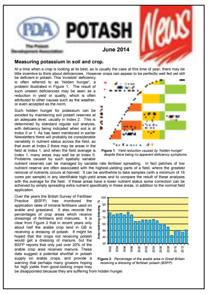
Potassium is an essential plant macro-nutrient that is taken up by crops from the soil. Potassium has been described as the 'quality element', ensuring optimum quality of agricultural produce, lowering production costs and reducing the risk of rejection when the produce is offered for sale. The impact potassium has on agricultural produce at many levels is shown in this infographic from IPI.

The infographics are also available on our website (http://www.ipipotash.org/infographics.php).

For hardcopies of the publication or infographics please contact IPI head office at ipi@ipipotash.org with a return postal address.

Publication by the PDA

Measuring Potassium in Soil and Crop



POTASH News, Spring 2014.

At a time when a crop is looking at its best, as is usually the case at this time of year, there may be little incentive to think about deficiencies. However crops can appear to be perfectly well fed yet still be deficient in potash. This 'invisible' deficiency is often referred to as 'hidden hunger'. Read more on the PDA website.

Potash Development Association (PDA) is an independent organisation formed in 1984 to provide technical information and advice in the UK on soil fertility, plant nutrition and fertilizer use with particular emphasis on potash. See also www.pda.org.uk.

Scientific Abstracts

K in the Literature

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Nutrient Management Decision Tool for Small-Scale Rice and Maize Farmers

R.J. Buresh, R. Castillo, M. van den Berg, and G. Gabinete. 2012. FFTC Technical Bulletin 190.

Abstract: Site-specific nutrient management (SSNM), as developed for rice (*Oryza sativa* L.) through partnerships of the International Rice Research Institute (IRRI) with organizations across Asia, provides scientific principles for determining field-specific fertilizer nitrogen (N), phosphorus (P), and potassium (K) requirements for cereal crops. These SSNM-based principles enable the determination of crop requirements for fertilizer N using a yield gain approach, the distribution of fertilizer N to match critical crop growth stages, and the determination of crop requirements for fertilizer P and K using a field-level nutrient balance approach. The uptake by farmers of improved nutrient management based on SSNM requires transforming the scientific principles into locally adapted tools that enable rapid development and implementation of nutrient management practices that match field-specific cropping conditions. We used recent advances in information and communication technology (ICT) and mobile phones to develop Web and mobile phone applications of "Nutrient Manager for Rice" (www.irri.org/nmrice), which transform the science of SSNM into guidelines matching the field specific needs and conditions of a farmer. Nutrient management guidelines provided by "Nutrient Manager" are calculated by a 'model' residing on a cloud-based server. Information obtained by the 'model' from answers of farmers to questions about their location-specific cropping conditions can be supplemented with Internet-based soils information to enhance the robustness of nutrient management guidelines provided to farmers. Field trials with rice reveal no relationship between soil analyses for soil N, P, or K status and field-measured rice response to the added nutrient. There is consequently an immediate need to identify soil information most indicative of crop requirements for supplemental nutrient in small landholding with large spatial and temporal variations in management, nutrient balances, and yield.

Soil Nutrient Management Based on Soil Information System in Korea

Yejin Lee, Hong-Bae Yun, Seong-Sooo Kang, Suk-Young Hong, Jong-Sik Lee, and Deog-Bae Lee. 2012. FFTC Technical Bulletin 191.

Abstract: The Soil Information System (SIS) in Korea has been developed to manage the soil fertility and soil resources for sustaining agricultural production. To manage the fertilization, the fertilizer application rates were established considering soil nutrient contents and crop requirements. The fertilizer recommendation program in the soil information system is based on the fertilization equation by soil testing, and it provides the farmer with soil information such as soil physical and chemical properties, and fertilizer application rates. Through this system, the farmer can apply fertilizers economically, and the soil-testing database can be used to establish the fertilizer supply policy.

Phosphorus and Potassium Decision Support System: Bridging Soil Database and Fertilizer Application

Sulaeman, Y., D. Nursyamsi, L.R. Widowati, Husnaen, and M. Sarwani. 2012. FFTC Technical Bulletin 192.

Abstract: This paper discusses the Phosphorus and Potassium Decision Support System (PKDSS) developed by ICALRD and its role in bridging soil database and fertilizer application. This system is a fertilizer recommendation model, as well as a computer program, used as a tool in determining fertilizer requirement for a given crop based on soil testing. In Indonesia, balanced fertilizer application approach is adopted to increase crop production while reducing negative impact on environment. This approach requires a better insight on soil characteristics and behavior. The soil nutrient status determines fertilizer recommendation for a given crop. The PKDSS recommends fertilizer rate after correcting the standard rate by its correction factor. The correction factor indicates the effect of selected soil properties on soil nutrient dynamics. N-fertilizer is corrected by soil texture class and soil organic carbon content. P-fertilizer is corrected by soil texture class, soil pH, soil organic carbon content, and P-retention. K-fertilizer is corrected by soil texture class, soil organic carbon content, and cation exchange capacity of clay. PKDSS needs 14 soil properties as input, divided into two layers: first layer to select the standard recommendation and second layer to determine the correction factor. These soil properties can be provided by soil data stored in the soil database. These legacy data can be used to create quantitative soil property maps by using digital soil mapping techniques. These maps are inputted to PKDSS to come up with fertilizer recommendation area (FRA) for a given crop. The FRA assists the local government in planning fertilizer stock and distribution in each agricultural service. PKDSS plays an important role in bridging soil database and fertilizer application.

Significance of Potassium Use in Haryana Agriculture

Singh, J.P., K.S. Grewal, and R.S. Antil. 2014. Indian J. Fert. 10(2):30-38.

Abstract: Consumption of potassic fertilisers has increased in the state of Haryana. However, the quantity of fertilizer use is not only imbalanced but inadequate to meet the requirements of plant demand for optimum yield. The judicious fertilizer use takes into consideration the nutrient status of the soils as well as crop responses to fertilizer applications. The present paper outlines the results of a systematically GPS based recently conducted survey analysis for K status of Haryana soils. Overall, more than 73% soils falling under low to medium category in available K indicate an alarming situation of the depleting scenario of K status in the state and emphasizes the need for the application of potassic fertilisers for maintaining crop yields and nutrient status. The study also shows the growing responses of K application under different crops and cropping systems. Based on the results of different on site and farm field experiments, new recommendations for K in crops viz., pearl millet, cluster bean, mustard and sugarcane have been advocated and has been recently included in the package of practices for kharif and rabi crops in Haryana. It is suggested that readily available pools of potassium do not clearly synchronise with the K uptake/removal by crops and for a better picture on K supplying power of soils the non-exchangeable K pool of the soil should be periodically and simultaneously monitored.

Distribution of Forms of Potassium in Relation to Different Agroecological regions of North-Eastern India

Reza, S.K., Utpal Baruah, T. Chattopadhyay, and Dipak Sarkar. 2014. Archives of Agronomy and Soil Sciences 60(4-6):507-517. DOI 10.1080/03650340.2013.800943.

Abstract: Distribution of potassium (K) in soils is governed by the agroecological region (AERs), as the operational intensity of factors and processes of soil formation vary with AER. Therefore, we aimed at finding out the relationship between the forms of K (K forms) with AER and the association of K forms with soil properties in the North-Eastern region of India. For this, horizon-wise soil samples were collected from pedons, three each from three AERs (15 (hot sub-humid to humid), 16 (warm per-humid) and 17 (warm per-humid with less cool winter)) in the North-Eastern India. The water balance diagram for AER shows that precipitation (P) exceeds the potential evapo-transpiration (PET) from June to October, AER 16 shows almost no period when the PET is more than the P and AER 17 shows that the region experiences only a short water deficit of 100-150 mm during post-monsoon period. Soil samples were analysed for physical and chemical properties and K forms. The soils were acidic to neutral with low cation exchange capacity (CEC). The water-soluble K ranged between 0.006 and 0.144 cmol kg^{-1}, exchangeable K

between 0.07 and 0.54 cmol kg^{-1}, fixed K from 16.7 to 61.3 cmol kg^{-1} and total K from 17.4 to 63.6 cmol kg^{-1} in soils of different horizons. Further, the results revealed that all the K forms followed the trend of AER 16 >AER 17 >AER 15. Exchangeable K showed higher correlation with clay ($r = 0.519^{**}$), while fixed K with organic carbon ($r = 0.390^{*}$).

Nutrient Efficiency of Different Crop Species and Potato Varieties – in Retrospect and Prospect

Trehan, S.P., and B.P. Singh. 2013. Potato J. 40(1):1-21.

Abstract: Different plant species and potato cultivars differed in nutrient use efficiency. Earlier studies indicated that potato cv. Kufri Pukhraj was the most N, P and K efficient cultivar among released cultivars tested in the absence as well as presence of green manure. The efficient cultivars gave higher tuber yield under N, P and K stress (i.e. with less dose of N, P and K fertilizer) and had higher agronomic use efficiency (AUE) than less efficient cultivars. The main cause of higher nitrogen efficiency in the presence of green manure was the capacity of a genotype to use/absorb more N per unit green manured soil. The variation in phosphorus and potassium efficiency of different potato cultivars was due to both their capability to use absorbed P and K to produce potato tubers (PUE) and to their capacity to take up more P and K per unit soil (NUE). Further comparison of nutrient (N, P and K) efficiency of promising potato hybrid JX 576, now released as Kufri Gaurav, with Kufri Pukhraj revealed that hybrid JX 576 is more N, P and K stress tolerant than Kufri Pukhraj. Its higher efficiency was mainly because of its better utilization of absorbed nutrients (N, P and K) for potato production than other cultivars. The higher expression of ammonium transporter, cytochrome oxidase and asparagine synthetase in leaves can be used as parameters to screen potato genotypes for high metabolism, utilization, transport and storage of N. This review brings out the need to establish linkage of nutrient efficiency with root and shoot parameters/DNA markers/genes.

Effect of Integrated Nutrient Management Practices on Yield of Potato

Sumati Narayan, Raihana H. Kanth, Raj Narayan, Farooq A. Khan, Parmeet Singh, and Shabir U. Rehman. 2013. Potato J. 40(1):84-86.

Potato is one of the leading commercial crops of Kashmir valley and is cultivated on an area of about 2500 ha with the production and productivity of 32.5 thousand t and 13 t/ha, respectively (Anonymous, 2009). Being a heavy feeder of nutrients, potato requires high amount of nitrogen, phosphorus and potassium. Chemical fertilizers are the main source of nutrients used for potato cropping. However, continuous dependence on chemical fertilizers causes nutritional imbalance and adverse effects on physico-chemical and biological properties of the soil. Integrated nutrient management (INM) is a better approach for supplying nutrition or food to the crop by including organic and inorganic sources of nutrients (Arora, 2008). Keeping the facts in view, the present investigation was planned to find out the appropriate combination of organic and inorganic sources of nutrients and bio-inoculants for improving yield of potato under temperate condition of Kashmir valley.

Spatial Distribution of Soil Available Nutrients in the Potato Growing Pockets of Hoshiarpur District of Punjab

Jatav, M.K., V.K. Dua, Manoj Kumar, S.P. Trehan, and Sushil Kumar. 2013. Potato J. 40(2):128-134.

Abstract: Soil samples of potato growing pockets of Hoshiarpur district of Punjab were collected and analysed for pH, OC and available NPK. The soil analysis data was fed into GIS software and spatial maps generated. The soils of the district in general, were slightly acidic to slightly alkaline in reaction. The pH of collected soil samples varied from 5.0 to 8.2 with a mean value of 6.8. About 90 percent of the total area had pH less than 7.5, a situation considered much suitable for potato cultivation. The organic carbon ranged from low to medium (0.2 to 0.7%) with an average value of 0.4 percent. Available nitrogen ranged from 186.3 to 355.6 kg/ha with a mean value of 242.5 kg/ha and more than 88 percent of samples had available phosphorus greater than 20 ppm. None of the collected sample were deficient in available phosphorus, suggesting build-up of P fertilizers in these areas. In case of available soil potassium, 79, 19.2 and 2 percent samples were found to be low, medium and high, respectively. After kriging, results showed that 30.5 and 18.8% area had high and very high phosphorus, respectively, but were low in nitrogen and potassium. About 17.3 percent area was medium in available nitrogen, very high in phosphorus but low in available potassium, while 12.8% area was medium in both available N and K but very high in P.

Five Ideas that have Changed Research in the Cropping Sector

Crole-Rees A., V. Nassar, A. Schori, W. Kessler, and B. Jeangros. 2014. Recherche Agronomique Suisse 5(1):4-11.

Abstract: Innovation is now a prerequisite for institutions aiming to maintain their competitiveness in a more and more liberalized economy. This is also true for agricultural research. One of the objectives of ProfiCrops, the research program Agroscope, was to promote the innovation process leading to added value in the cropping sector. This article describes five ideas, their development into innovation and the scope for the innovation's adoption. The sampling was done purposively, based on an

innovations' list for the cropping sector. The sample comprised: three process innovations: a portable Near-infrared spectroscopy (NIRS) tool, the sequence of the fire blight pathogen genome and the use of molecular markers, and two service innovations: Life Cycle Assessment (LCA) in agriculture and urban agriculture. The results show that the innovation process within research requires some scope that includes a clear research mission, sufficient financial resources, time and a risk-taking attitude.

Effects of Many Years of Organic Agriculture

Honegger, A., R. Wittwer, D. Hegglin, H.-R. Oberholzer, A. de Ferron, P. Jeanneret, and M. Van der Heijden. 2014. Recherche Agronomique Suisse 5(2):44-51.

Abstract: More and more farmers consider to switch from conventional to organic production. What effect, then, does this have on yield and environmental performance? In particular, the question of how the duration of organic management affects plant yield, weed populations, biodiversity and soil fertility has rarely been investigated. To investigate this question, we compared 34 plots distributed over four farm categories – conventional, recently converted, and «new» and «old» organic farms. Our study shows that crop yield and soil fertility remain constant as length of time under organic management increases. Similarly, weed pressure has not increased along with duration of organic management. Weed abundance did, however, vary strongly among fields, with problematic weeds being highly abundant at specific field sites. This study demonstrates that duration of organic management does not have a negative impact on either plant yield or soil fertility on mixed-economy farms under Swiss conditions.

Synergies and Trade-Offs with regard to Ensuring Food Security and the Efficient Use of Resources

Kopainsky, B., T. Tribaldos, C. Flury, M. Pedercini, and H. Lehmann. 2014. Recherche Agronomique Suisse 5(4):132-137.

Abstract: In Switzerland, agriculture and the food industry are facing major challenges, as is society in general. The gap between desired and achievable levels of food production is growing wider, since ensuring sufficient food supplies for a growing population requires a constant increase in production while at the same time it is necessary to reduce the use of resources. By applying a dynamic simulation model to the situation in Switzerland it was possible to quantify the trade-offs and synergies between environmental and production outcomes with a time horizon of 2050. The aim of this project was to identify the key conditions for ensuring both long-term food provision and the efficient use of resources. The main finding arising from the application of the model was that Swiss agriculture has the potential to reconcile the aims of food provision and environmental protection; however, implementing the key conditions will depend inter alia upon technical and organisational progress that goes beyond the currently foreseeable possibilities.

Global Food Security – The Consequences for Switzerland

Becker, B., M. Zoss, and H.-J. Lehmann. 2014. Recherche Agronomique Suisse 5(4):138-145.

Abstract: Society is facing major challenges in ensuring global food security. Global trends since the food-price crisis in 2008 have revealed significant new risks. In 2012, the Swiss Federal Office for Agriculture decided to identify, quantify and prioritise these risks and to derive potential areas of intervention. A literature review based on the analysis of key publications (Subproject 2) provides a global perspective on the global food security situation and future projections. The literature study identified seven drivers influencing the future of the global food security system: (i) population growth; (ii) climate change; (iii) environmental degradation and competition for land, water and energy resources; (iv) changing dietary patterns and consumer preferences; (v) rise in, and volatility of food prices; (vi) increasing vertical integration of value chains in food production and markets; (vii) technological progress. The report identifies six intervention areas for which conclusions and options for action are suggested: (i) agricultural production; (ii) environmental sustainability and resource efficiency; (iii) dietary patterns; (iv) trade policies and the role of multinational food companies; (v) research and innovation; and (vi) international cooperation.

Mechanisms and Physiological Roles of K^+ Efflux from Root Cells

Demidchik, V. 2014. J. Plant Physiology 171(9):696-707. DOI 10.1016/j.jplph.2014.01.015.

Abstract: Potassium is the most abundant macronutrient, which is involved in a multitude of physiological processes. Potassium uptake in roots is crucial for plants; however, K^+ efflux can also occur and has important functions. Potassium efflux from roots is mainly induced by stresses, such as pathogens, salinity, freezing, oxidants and heavy metals. Reactive oxygen species (ROS) and exogenous purines also cause this reaction. The depolarisation and activation of cation channels are required for K^+ efflux from plant roots. Potassium channels and nonselective cation channels (NSCCs) are involved in this process. Some of them are 'constitutive', while the others require a chemical agent for activation. In Arabidopsis, there are 77 genes that can potentially encode K^+-permeable channels. Potassium-selective channel genes include 9 Shaker and 6 Tandem-Pore K^+ channels. Genes of NSCCs are more abundant and present by 20 cyclic nucleotide gated channels, 20 ionotropic glutamate receptors,

1 two-pore channel, 10 mechanosensitive-like channels, 2 mechanosensitive 'Mid1-Complementing Activity' channels, 1 mechanosensitive Piezo channel, and 8 annexins. Two Shakers (SKOR and GORK) and several NSCCs are expressed in root cell plasma membranes. SKOR mediates K^+ efflux from xylem parenchyma cells to xylem vessels while GORK is expressed in the epidermis and functions in K^+ release. Both these channels are activated by ROS. The GORK channel activity is stimulated by hydroxyl radicals that are generated in a Ca^{2+}-dependent manner in stress conditions, such as salinity or pathogen attack, resulting in dramatic K^+ efflux from root cells. Potassium loss simulates cytosolic proteases and endonucleases, leading to programmed cell death. Other physiological functions of K^+ efflux channels include repolarisation of the plasma membrane during action potentials and the 'hypothetical' function of a metabolic switch, which provides inhibition of energy-consuming biosyntheses and releasing energy for defence and reparation needs.

Is the Leaf Bundle Sheath a "Smart Flux Valve" for K⁺ Nutrition?

Wigoda, N., M. Moshelion, and N. Moran. 2014. J. Plant Physiology 171(9)715-722. DOI 10.1016/j.jplph.2013.12.017.

Abstract: Evidence has started to accumulate that the bundle sheath regulates the passage of water, minerals and metabolites between the mesophyll and the conducting vessels of xylem and phloem within the leaf veins which it envelops. Although potassium (K^+) nutrition has been studied for several decades, and much is known about the uptake and recirculation of K^+ within the plant, the potential regulatory role of bundle sheath with regard to K^+ fluxes has just begun to be addressed. Here we have collected some facts and ideas about these processes.

Cellular and Tissue Distribution of Potassium: Physiological Relevance, Mechanisms and Regulation

Ahmad, I., and F.J.M. Maathuis. 2014. J. Plant Physiology 171(9):708-714. DOI: 10.1016/j.jplph.2013.10.016.

Abstract: Potassium (K^+) is the most important cationic nutrient for all living organisms. Its cellular levels are significant (typically around 100 mM) and are highly regulated. In plants K^+ affects multiple aspects such as growth, tolerance to biotic and abiotic stress and movement of plant organs. These processes occur at the cell, organ and whole plant level and not surprisingly, plants have evolved sophisticated mechanisms for the uptake, efflux and distribution of K^+ both within cells and between organs. Great progress has been made in the last decades regarding the molecular mechanisms of K^+ uptake and efflux, particularly at the cellular level. For long distance K^+ transport our knowledge is less complete but the principles behind the overall processes are largely understood. In this chapter we will discuss how both long distance transport between different organs and intracellular transport between organelles works in general and in particular for K^+. Where possible, we will provide examples of specific genes and proteins that are responsible for these phenomena.

The Twins K⁺ and Na⁺ in Plants

Begoña, B., R. Haro, A. Amtmann, T.A. Cuin, and I. Dreyer. 2014. J. Plant Physiology 171(9):723-731. DOI 10.1016/j.jplph.2013.10.014.

Abstract: In the earth's crust and in seawater, K^+ and Na^+ are by far the most available monovalent inorganic cations. Physico-chemically, K^+ and Na^+ are very similar, but K^+ is widely used by plants whereas Na^+ can easily reach toxic levels. Indeed, salinity is one of the major and growing threats to agricultural production. In this article, we outline the fundamental bases for the differences between Na^+ and K^+. We present the foundation of transporter selectivity and summarize findings on transporters of the HKT type, which are reported to transport Na^+ and/or Na^+ and K^+, and may play a central role in Na^+ utilization and detoxification in plants. Based on the structural differences in the hydration shells of K^+ and Na^+, and by comparison with sodium channels, we present an ad hoc mechanistic model that can account for ion permeation through HKTs.

Organelle-Localized Potassium Transport Systems in Plants

Hamamoto, S., and N. Uozumi. 2014. J. Plant Physiology 171(9):743-747. DOI 10.1016/j.jplph.2013.09.022.

Abstract: Some intracellular organelles found in eukaryotes such as plants have arisen through the endocytotic engulfment of prokaryotic cells. This accounts for the presence of plant membrane intrinsic proteins that have homologs in prokaryotic cells. Other organelles, such as those of the endomembrane system, are thought to have evolved through infolding of the plasma membrane. Acquisition of intracellular components (organelles) in the cells supplied additional functions for survival in various natural environments. The organelles are surrounded by biological membranes, which contain membrane-embedded K^+ transport systems allowing K^+ to move across the membrane. K^+ transport systems in plant organelles act coordinately with the plasma membrane intrinsic K^+ transport systems to maintain cytosolic K^+ concentrations. Since it is sometimes difficult to perform direct studies of organellar membrane proteins in plant cells, heterologous expression in yeast and *Escherichia coli* has been used to elucidate the function of plant vacuole K^+ channels and other membrane transporters. The vacuole is the largest organelle in plant cells; it has an important task in the K^+ homeostasis of the cytoplasm. The initial electrophysiological measurements of K^+ transport have categorized three classes of plant vacuolar cation

channels, and since then molecular cloning approaches have led to the isolation of genes for a number of K^+ transport systems. Plants contain chloroplasts, derived from photoautotrophic cyanobacteria. A novel K^+ transport system has been isolated from cyanobacteria, which may add to our understanding of K^+ flux across the thylakoid membrane and the inner membrane of the chloroplast. This chapter will provide an overview of recent findings regarding plant organellar K^+ transport proteins.

K^+ Uptake in Plant Roots. The Systems Involved, their Regulation and Parallels in other Organisms

Nieves-Cordones, M., F. Alemán, V. Martínez, and F. Rubio. 2014. J. Plant Physiology 171(9):688-695. DOI 10.1016/j.jplph.2013.09.021.

Abstract: Potassium (K^+) is an essential macronutrient for plants. It is taken into the plant by the transport systems present in the plasma membranes of root epidermal and cortical cells. The identity of these systems and their regulation is beginning to be understood and the systems of K^+ transport in the model species *Arabidopsis thaliana* remain far better characterized than in any other plant species. Roots can activate different K^+ uptake systems to adapt to their environment, important to a sessile organism that needs to cope with a highly variable environment. The mechanisms of K^+ acquisition in the model species A. thaliana are the best characterized at the molecular level so far. According to the current model, non-selective channels are probably the main pathways for K^+ uptake at high concentrations (>10 mM), while at intermediate concentrations (1 mM), the inward rectifying channel AKT1 dominates K^+ uptake. Under lower concentrations of external K^+ (100 µM), AKT1 channels, together with the high-affinity K^+ uptake system HAK5 contribute to K^+ acquisition, and at extremely low concentrations (<10 µM) the only system capable of taking up K^+ is HAK5. Depending on the species the high-affinity system has been named HAK5 or HAK1, but in all cases it fulfills the same functions. The activation of these systems as a function of the K^+ availability is achieved by different mechanisms that include phosphorylation of AKT1 or induction of HAK5 transcription. Some of the characteristics of the systems for root K^+ uptake are shared by other organisms, whilst others are specific to plants. This indicates that some crucial properties of the ancestral of K^+ transport systems have been conserved through evolution while others have diverged among different kingdoms.

Going Beyond Nutrition: Regulation of Potassium Homoeostasis as a Common Denominator of Plant Adaptive Responses to Environment

Anschütz, U., D. Becker, and S. Shabala. 2014. J. Plant Physiology 171(9):670-687. DOI 10.1016/j.jplph.2014.01.009.

Abstract: Partially and fully completed plant genome sequencing projects in both lower and higher plants allow drawing a comprehensive picture of the molecular and structural diversities of plant potassium transporter genes and their encoded proteins. While the early focus of the research in this field was aimed on the structure–function studies and understanding of the molecular mechanisms underlying K^+ transport, availability of *Arabidopsis thaliana* mutant collections in combination with micro-array techniques have significantly advanced our understanding of K^+ channel physiology, providing novel insights into the transcriptional regulation of potassium homeostasis in plants. More recently, posttranslational regulation of potassium transport systems has moved into the center stage of potassium transport research. The current review is focused on the most exciting developments in this field. By summarizing recent work on potassium transporter regulation we show that potassium transport in general, and potassium channels in particular, represent important targets and are mediators of the cellular responses during different developmental stages in a plant's life cycle. We show that regulation of intracellular K^+ homeostasis is essential to mediate plant adaptive responses to a broad range of abiotic and biotic stresses including drought, salinity, and oxidative stress. We further link post-translational regulation of K^+ channels with programmed cell death and show that K^+ plays a critical role in controlling the latter process. Thus, it appears that K^+ is not just the essential nutrient required to support optimal plant growth and yield but is also an important signaling agent mediating a wide range of plant adaptive responses to environment.

Split Application of Potassium Improves Yield and End-Use Quality of Winter Wheat

Qiang Lua, Dianyong Jiaab, Yu Zhanga, Xinglong Daia, and Mingrong He. 2014. Agron. J. 106(4):1411-1419. DOI 10.2134/agronj13.0202.

Abstract: Many studies have investigated the effects of basal K fertilization on the yield and quality of wheat (*Triticum aestivum* L.). However, less is known about the influence of the split

application of K on yield, size distribution of protein fractions, and quality of wheat. Field studies were conducted in two successive seasons (2010/2011 and 2011/2012) using four winter wheat cultivars, Jimai 20, Gaocheng 8901, Yannong 19, and Jinan 17, and three regimes of K fertilization (K0: no K fertilization; KB: basal K fertilization of 120 kg ha^{-1}; KS: basal K fertilization of 60 kg ha^{-1} plus topdressing of 60 kg ha^{-1} at jointing). The yield and its components, protein composition, dough-mixing properties, and bread-making quality were determined after harvesting. On average, the KS treatments had a yield advantage over KB treatments mainly resulting from higher kernel weight. The KS treatments improved wheat quality resulted in increased glutenin/gliadin ratio, higher polymerization index (the ratio of sodium dodecyl sulfate to insoluble glutenin in total glutenin), and larger glutenin macropolymer (GMP) particles compared to KB fertilization. No differences in the content of crude protein and wet gluten were found between the KS and KB treatments. Dough development time, stability time, and loaf volume were positively correlated with the glutenin/gliadin ratio, polymerization index, and average size of the GMP, respectively. These results suggest that KS can improve the yield and end-use quality of winter wheat.

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