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

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Abstract

Pakistan is located in the sub-tropical zone and soils are deficient in a number of plant nutrients especially nitrogen (N) and phosphorus (P). 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

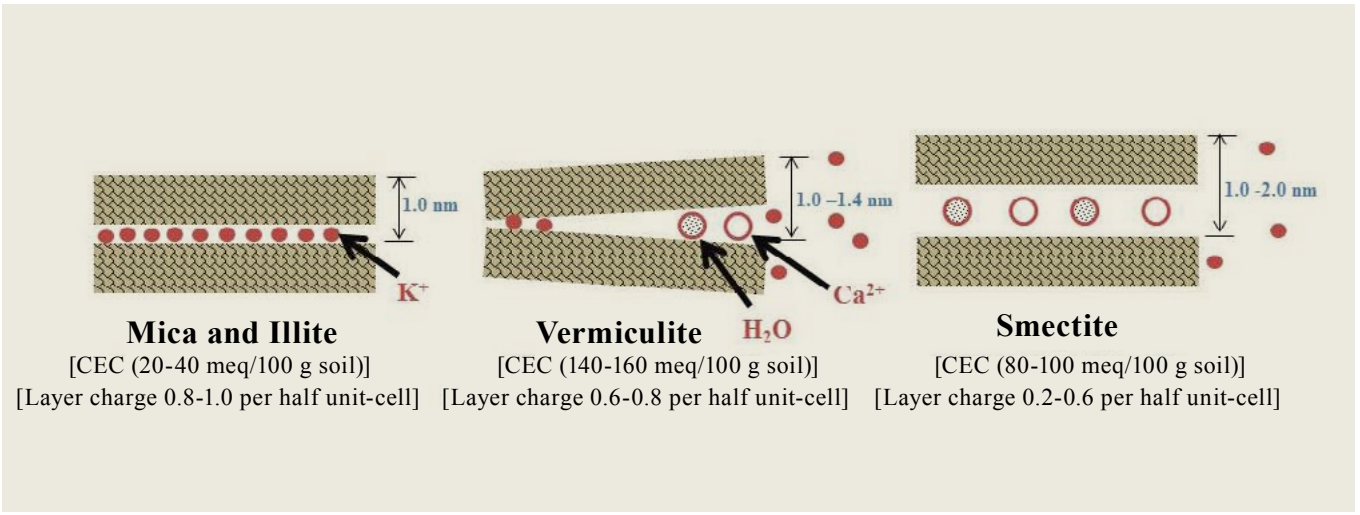

Fig. 1. Properties of four types of clay minerals often present in agricultural soils. Adapted from Wakeel *et al.*, 2013.

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

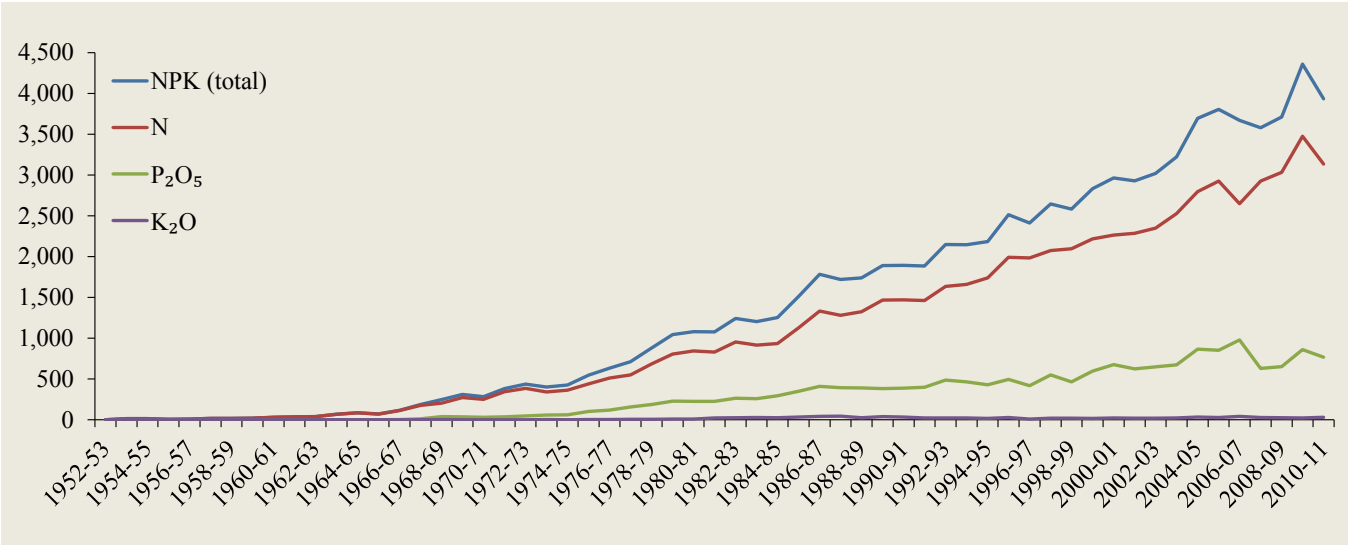

Fig. 2. Chemical fertilizer use (N, P and K) in Pakistan from 1952-2011. *Source:* Economics Survey of Pakistan, 2012-13.

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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