Potassium Research in India: Past and Future

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Introduction

Potassium research is best appreciated in the context of agricultural research since bulk of potassium is utilized on farms. Agriculture is a major cornerstone in national economy and the country is still confronted with a substantially increasing population pressure.

Agricultural Research in India formally started about the beginning of the twentieth century. In 1905, following up on the recommendations of the Famine Enquiry Commission, the Government of India established an agricultural research institute at Pusa in the then Darbhanga district of Bihar. In 1928, the Royal Commission on Agriculture observed that the soil of Pusa farm, though well suited for growing most of the important Indian Crops, is not typical of any larger area in the province it was situated. Fortunately, however, realizing that a central institution under the control of the Government of India would be of limited value unless there was simultaneously a good development of agriculture in the provinces, as early as 1905, the Government took steps for the development of agricultural research and education in the provinces. In pursuance of this scheme, colleges were started or reorganized at Pune, Kanpur, Nagpur, Lyallpur (now Faisalabad, in Pakistan), Coimbatore and Lahore. Some provincial governments took more interest in the subject than others, depending upon the state of provincial resources.

The limited research that was undertaken in India was managed and executed largely by colonial officials. This was intended to improve the quality of export crops which included cotton, jute, beverages such as tea and coffee, spices and other commodities such as sugar. In order to promote, guide and coordinate agricultural research throughout India and to link it with agricultural research in other parts of the British Empire, the Royal Commission proposed constitution of Imperial (now Indian) Council of

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Agricultural Research (ICAR) that came into being in 1930. Initially, it did not exercise any administrative control over the central or provincial research institutions.

Although Dr. J.A. Voelcker, a consulting Chemist to the Royal Agricultural Society, happened to be the first scientist deputed to India by British Government as early as 1889, to advise upon the best course of action to apply the teachings of agricultural chemistry, the chemicalization of agriculture had to wait for several decades. General poverty of Indian soils in nitrogen and lack of availability of synthetic nitrogen compounds prevented large-scale experimentation with chemical fertilizers. After the technology of ammonia reactors was perfected, Imperial Chemical Industries assisted in the conduct of field experiments, mostly in plant industry institutes and Government research stations. In mid-forties, A. B. Stewart of the Macaulay Institute of Soil Research, Aberdeen was invited by the then British Government to report on soil fertility investigations in India. His report concluded that Indian soils were generally poor in nitrogen. These did not require phosphate, but legumes, particularly Egyptian clover, shallow-rooted wheat crop, in certain parts of the Punjab and crops raised in light textured red soils responded to fertilizer phosphorus. Most Indian soils, apart from laterites, were relatively well supplied with potassium but the response to K in the presence of adequate supplies of other nutrient had not been adequately studied . There were indications that trace element deficiencies in Indian soils might be comparatively widespread with intensification of agriculture. Even if all available waste, organic and other materials likely to be of manurial value are carefully conserved and returned to the land, supplies would still be inadequate to improve and maintain soil fertility at a high level of crop yield.

Developments in Organizing Potassium Research

The most notable change in the landscape of potassium research in India has been a very substantial expansion of work during the last 5 decades. A limited research on potassium was initially undertaken by ICAR institutes, Departments of Agricultural Chemistry in agricultural colleges and by potascheme. Indian Agricultural Research Institutes, various state agricultural universities and ICAR institutes undertook laboratory and field investigation largely through post graduate research. Pioneering work of field trials by potascheme and subsequently by Indian Potash Limited supplemented the efforts of the ICAR and state agricultural research systems, and established the need for potassium in large areas for many crops.

Stewart's report was the basis of work since mid-fifties in simple fertilizer trials in different districts of Indian states and a chain of multi-factorial agronomic experiments at various research stations throughout the country. A chain of soil testing laboratories started in the country beginning 1956, provided a general idea of the fertility status of Indian soils. Considerable work was done at various institutions on methods and procedures to assess the availability of plant nutrients in the soils. A coordinated project on soil test – crop response correlation has attempted to develop equations to relate crop yields with laboratory estimates of soil fertility and fertilizer amounts. Another coordinated project on long-term fertilizer use has indicated situations where initially non-responsive soils gradually started responding to potassium. Intensive cultivation brought into light widespread deficiencies of nutrients, besides nitrogen, of phosphorus, potassium, sulphur and zinc.

Setting up of the Potash Research Institute of India in 1977 was a major initiative by the Indian Potash Limited. It was an outcome of the faith on the part of an enlightened industry that an enduring market development must have as its basis – the scientific truth. However, for practical reasons, the institute focussed on purposeful research.

While it was realized that plantation crops like tea, coffee, spices, rubber, tobacco, and tuber crops, and fruit crops like banana and grapes have substantial needs of fertilizer potassium, deficiencies of potassium in other crops were felt generally in areas of high crops yields and more so in situations where continued nitrogen fertilization, with or without phosphorus, depletes the soils of their potassium. Hence, with the passage of time and intensification of agriculture, potassium availability in the soils tends to decline. A good delineation of potassium deficiency in major Indian soils, was therefore, one objective of research at the Potash Research Institute of India. Fertility maps, prepared from analyses of soil samples, collected without any systematic plan, not only suffer from lack of representative character but average estimates of potassium fertility fail to offer practical guidance for fertilizer use by the farmer. Soil fertility investigations carried out on the basis of pedological classification, such as soil series, have easier applicability. Soil types within a series recognize differences in texture which are easily perceived by the farmers. Recommendations based on soil series can be extended to similar areas with a greater degree of confidence. Hence, the institute programmed studies on benchmark soils. A comparison of soil test estimates at periodic intervals informs one about the developing situation on potassium deficiency. Use of benchmark soils for potassium fertility delineation provides an easy opportunity for such a comparison. Monitoring of the changes in available potassium under prevalent management conditions was another worthwhile objective of potassium research.

Soil testing commonly employs the ammonium acetate extraction procedure for estimating potassium fertility of soils but laboratories throughout the country use the same critical limits to label them sufficient or deficient. However, there is reason to believe that critical limits of potassium differ for different soils and crops. Some soils have larger reserves of potassium than others, even though the ammonium acetate extractable potassium is similar. Also crops differ in the matter of their rooting habits, length of growing season and amount of potassium removal. Therefore, Potash Research Institute considered it imperative to try to define the soils test limits for different soils and crops.

Potassium exists in soils as a structural element of soil minerals, fixed between clay mineral lattice, adsorbed on exposed surfaces of minute soil particles and in soil solution. Potassium at the time of absorption by plants must exist in solution or exchangeable forms. The rate at which solution and exchangeable potassium, are renewed by the lattice and non-exchangeable potassium, determines the significance of the quantities of solution and exchangeable potassium. The amount of lattice and non-exchangeable potassium and the rate of release of potassium from these sources depends on the nature and abundance of potassium bearing minerals. The Potash Research Institute therefore, thought it essential to study the mineralogy of soil potassium of typical Indian soils, in order to understand their behaviour in the matter of release of native and fixation of fertilizer potassium and develop a better basis for fine tuning of soil test methodology.

Potassium is known to be susceptible to luxury consumption, under conditions of excess potassium in the growth medium. Since potassium is costly, it was considered, desirable to know the minimum optimum amount of potassium in plant tissues for obtaining top yields. This information can form the basis of plant analysis for diagnostic purposes, which together with soil testing can be used in nutrient indexing surveys of benchmark soils. A large acreage of cropland in India is rainfed. Plants with adequate potassium lose less moisture because of the reduced transpiration rate. When exposed to desiccating winds, plants supplied with adequate potassium are able to close the stomata much more quickly than potassium deficient ones. Hence, Potash Research Institute considered it useful to assess the need for extra potassium of plants growing under conditions of moisture stress vis-à-vis the neighboring irrigated plants.

Potassium is understood to help plants build up resistance against incidence of diseases and insect pests, lodging, moisture abnormalities and the like. Hence, one objective of potash Research Institute is to help collect information on the adequacy of level of soil potassium, which may act as insurance for minimizing damages.

Potash & Phosphate Institute of Canada – India (PPIC-I) programme was set up through funding from western Diversification programme of the Government of Canada in 1990. PPIC supports research on balanced fertilizer use with phosphorus and potassium along with other nutrients and crop husbandry practices for increasing agricultural production and achieving Maximum Economic yields of crops.

Some Significant Results of Potassium Research in India

Spurred by the foregoing considerations, work on potassium research in India has led to building up some information on mineralogy of its soil potassium, forms of potassium and their content in Indian soils, testing of soils for potassium availability, potassium uptake by crops, potassium and water relations in plants, potassium and crop resistance to diseases and pests, crop responses to soil application of potassium and fertilizer potassium, its needs and supplies.

Most alluvial soils have illite as the dominant mineral in their clay fraction and quartz – feldspar, quartz-mica or quartz alone as the dominant mineral in their silt fraction. All Black soils have smectite as the dominant clay mineral while quartz alone is the dominant mineral in the silt fraction in several soils and feldspar in others. All Red, laterite and acid-sulphate soils have kaolinite as the dominant clay mineral and generally quartz as the dominant mineral.

Potassium in increasing quantity but decreasing availability is commonly considered to occur in water soluble, exchangeable, non-exchangeable and mineral forms. With few exceptions, all the 29 benchmark soils examined by

Potash Research Institute have small amounts of water-soluble K. Exchangeable K is generally more in the vertisols and vertic type soils and in the fine-textured alluvial soils than in the red and lateritic soils, acidic alluvial soils with kaolinite as dominant clay mineral, and coarse-textured alluvial soils. Illite-dominant alluvial soils generally contain the most non-exchangeable K, followed by smectite-dominant soils. Kaolinite-dominant soils contain less non-exchangeable K. Total K is generally more in illitic alluvial soils. With the exception of some illite / mica-containing smectite- and kaolinite-dominant soils all other vertisols and vertic type soils and red and lateritic soils possessed less total K.

There occurs a considerable variation in the amount of water-soluble K as a proportion of exchangeable K, which suggests that for a given amount of exchangeable K, one soil may supply more K to plants than another. In general, illite-, and kaolinite-dominant soils have a larger proportion of water-soluble to exchangeable K than smectite-dominant soils; however, this ratio differs among soils. Desorption of K from soils having similar estimates of ammonium acetate extractable K may differ considerably. Soil series having different mineralogy show a wide variation in both nitric acid soluble and ammonium acetate extractable K. Kaolinitic soils have generally less than 600 ppm nitric acid soluble K and are also low in ammonium acetate extractable K. Illitic soils have generally more than 1200 ppm nitric acid soluble K but have modest amounts of ammonium acetate extractable K. Smectitic soils have intermediate amounts of nitric acid soluble K but have high amounts of ammonium acetate extractable K. Thus, kaolinitic soils are low both in available and reserve potassium and generally need supplementary application of fertilizer potassium for adequate plant growth and development. Illitic soils which have high amounts of reserve potassium but modest amount of available potassium are generally sufficient in the supply of potassium for crop growth and development. However, here too, there are differences in the relationship between exchangeable K and water-soluble K. Soils having high desorption of exchangeable K need to be watched for development of potassium deficiencies. Smectitic soils which have intermediate amounts of nitric acid soluble K but have high amounts of ammonium acetate extractable K are a category in themselves. In such a situation, ammonium acetate extractable K should not be able to sustain itself with dwindling of reserve (nitric acid soluble) K. Shallow black soils with only modest tendency to develop cracks are likely to show potassium deficiencies earlier than deep black soils which crack excessively and allow continual mixing of surface and sub-surface layers.

Soils containing predominantly smectitic or illitic clay minerals have higher buffer capacity and lower values of AR_0^K than the kaolinite dominant soils. Soils of fine texture commonly have higher buffer capacity and lower values of AR_0^K than those of coarse texture. Generally, the kaolinitic soils of Vijaypura and Nedumangad series, the kaolinite-dominant acidic alluvial soil of Balasahi series, the coarse textured illitic soil of Nabha series and Jagdishpur loam have poor buffer capacity. The AR_0^K is significantly associated with water soluble K. Labile K (K_L), K held on non-specific sites (K_0) and specific sites (K_R) is higher for black than for red and alluvial soils. The illite from the semiarid and humid region behave differently; the rate and extent of release of non-exchangeable K by ammonium ions largely depends on the stage of weathering of K containing minerals.

Exchangeable K has been generally regarded a reliable index of K removal by crops, and neutral normal ammonium acetate is satisfactory extractant for estimating available potassium in soils. Soil test values have been used to prepare fertility maps. Lack of representative character of sampling and the difficulty to locate sites of nutrient deficiency impose serious limitations on the use of these maps. Soil fertility investigations carried out on pedological basis appear to have an easy applicability. Use of benchmark soils facilitates periodical monitoring of changes in soil fertility. Potash Research Institute has conducted a detailed examination of benchmark soils in 29 soil series. Accordingly, nine soils (three acid alluvial, three red, two lateritic and one illite-dominant alluvial) were low in both available and reserve K; two soils were moderate in available but low in reserve K; seven were moderate in available but high in reserve K; four were high in both types of K; and five vertisols and vertic type soils as well as two alluvial soils showed high available K but low reserve K.

A study on periodical monitoring shows a considerable depletion in available K in soils of Nabha (Punjab), Rarha and Akbarpur (Uttar Pradesh), Hanrgram and Kharbona (West Bengal) and Vijaypura (Karnataka) soil series. Three other soils did not show much depletion in available K but there was considerable reduction in reserve K; these may begin to respond to fertilizer K in course of time. Hence the situation needs to be closely monitored for watching changes in potassium fertility.

Field crops generally absorb potassium faster than they absorb nitrogen or phosphorus or dry matter. However, the rate of K absorption during crop growth differs with the crop and conditions of its growth. A short duration crop of potato which must grow and also accumulate much carbohydrates during a short span of about two months may absorb about 1.5-2.0 kg K per hectare per day while a crop of wheat which occupies the field for about 5 months needs to remove about 0.5-0.6 kg K per hectare per day. Hence a soil which may not need supplementary application of potassium for growing wheat may need it for growing potato. Nutrient uptake profiles for all major typical crops in various major soil groups should be prepared to obtain information on nutrient removal at weekly intervals throughout the growth and development phases, in order to plan efficient nutrient management. Since nutrient concentrations in plant tissues change with stage of the plant and differ in different plant parts, critical nutrient ranges are a good guide to diagnose nutrient deficiency.

Water is the single most important constraint for crop growth in arid and semi-arid lands. Therefore, in these areas, the need for fertilizer is generally more under irrigated than under rainfed conditions, Among fertilizer elements, need for potassium is modified in several ways under conditions of moisture stress. While effective supply of native potassium is considerably reduced, need for potassium per unit of dry matter accumulation increases to check transpiration losses through cuticle development and stomatal regulation. However, the total need for potassium in stressed plants is generally less than in non-stressed plants. It should be useful to simulate conditions of moisture stress obtaining in typical rainfed areas, in the relevant soil and determine the potassium requirements of crops.

There are some reports that enhanced potassium nutrition decreases the content of reducing sugars in plants, by converting them into phenols, such as anthocyanin, levco anthocyanin, and anthoxanthin, which form the precursors for synthesis of several toxic compounds in the plant system that render the plant resistant to pests. In some instances, enhanced potassium nutrition causes rapid proteogenesis with concomitant deficiency of amino acids needed by insects to develop. Increase in lignification and scleranchymatous layer with enhanced K nutrition also acts as a mechanical barrier to pest invasion in potassium treated plants.

The picture of crop responses to potassium in India has been changing with time. Starting with early reports of substantial responses to potassium only in potato and groundnut, first laterites were universally reported to be deficient in potassium and then potassium application was considered necessary for obtaining high yields in many other parts of the country. The results of experiments conducted during 5 years (1977-78 to 1982-83) in 49 districts of India showed significant response to potassium up to 60 kg K_2O ha^{-1} for maize, rice, wheat and finger millet under irrigated conditions. Crop responses to potassium were more in light textured soils and under humid conditions. Even under rainfed conditions, crop responses to potassium in rice, wheat, maize, sorghum and finger millet were also significant, though up to 30 kg K_2O ha^{-1} in many such areas, while there was response to oilseed crops – groundnut and mustard in the range of 40-60 kg K_2O $ha^{-1.}$

Two other sets of observations are worth mentioning. One analysis of data on crop responses to potassium in experiments on cultivators' fields shows an interesting time series trend; the magnitude of response more than doubled in 8-10 years in all regions (Humid, sub-humid, arid and semi-arid), presumably owing to increase in potassium deficiency with time. Two, soils low in K in Jalandhar (Punjab) and Kanpur (U.P.) districts responded much more to dressing of potassium than soils, medium or high in potassium.

The new series of long-term fertilizer experiments started in 1971 show substantial responses to potassium in all alfisols and in 3 inceptisols at Bhubaneswar, Ludhiana and Delhi. However, initially response was observed at only one location. Hence, there is need to exercise much caution about deciding on the non-responsiveness of crops to potassium on the basis of short-term experiments.

The series of Maximum Economic yield experiments initiated in various parts of the country under the aegis of Potash Phosphate Institute of Canada show the magnitude of yield improvement which is possible with better nutrient management that invariably includes larger application of fertilizer potassium. High yields and low unit production costs not only enables farmers to make more profits but also indicate opportunities for sustainable farming, so important for the well beings of soils and the farmers who till them.

Looking Ahead

The tremendous success in increasing agricultural production in India during the last 5 decades is a matter of deep satisfaction to all those who have contributed to it in a myriad of ways. Over the next 25 years, and beyond, agricultural production will have to rise substantially in almost all crops.

According to an assessment by the National Academy of Agricultural Sciences, the 1.4 billion people of India by the year 2025 will require approximately 300 mt food grains, 40 mt oilseeds, 58 mt sugar, 23 m bales of cotton lint, 65 mt potatoes, 120 mt fruits besides more vegetables, tea, coffee, spices, fuel wood, etc.

In many ways, progress in agricultural production in the future will be increasingly difficult. There are few new areas for bringing under cultivation. Much of the currently cultivated area suffers from land degradation of varying intensity. In the judgement of the National Commission on Agriculture, some of the area currently under rice and wheat, which is agronomically unsuitable to these crops needs to be shifted to cultivation of coarse cereals. By raising rice on tube-well water, the central parts of Punjab have contracted the problem of declining water tables. For these areas, viable alternate cropping systems have to be developed which not only conserve ground water resources but also yield a favourable net income. In order to increase family incomes, in the midst of a scenario of growing population and unemployment/under employment, raising of high value crops-vegetables and fruits will receive greater attention in the future. High yielding crop cultivars have already saturated the countryside. Genetic improvement of the crops that yields another quantum jump may take time to fructify. Elements of good agronomy eg. Optimum date of sowing, seed rate and plant population, and appropriate weed control and plant protection measures are already part of the farm extension vocabulary. Current suggestions are directed to rationalize the use of agro-chemicals, generally reduce the cost of cultivation and consequently improve the sustainability of farming.

In this scenario of shrinking land and water resources bulk of the increases in crop production will come about with scientific use of fertilizers. Approximately 30-35 million tonnes of NPK from fertilizers carriers besides 10 million tonnes from organic and biofertilizer sources are expected to be used by about 2025 AD. Many soils, initially sufficient in native supplies of soil potassium to raise a crop of 2 t ha^{-1} may need external supplies of potassium to produce a bigger crop of 3-4 t ha^{-1}. Tea, coffee, spices, potatoes, bananas, other fruits, vegetables, sugarcane and cotton invariably require more potassium than the cereals. Also, even in currently potassium-deficient soils, fertilizer potassium is usually applied in amounts, which are a small fraction of the crop removal. Hence, the requirement of fertilizer potassium should increase proportionately more than that of nitrogen and phosphorus.

Thus, total need of fertilizer potassium for Indian soils around 2025 AD is surmised to be in the neighbourhood of 4 mt K_2O against 1997-98 consumption of 1.37 mt K_2O.

Looking to the future, it is very difficult to foresee any significant change in the programmes that have been chalked out for potassium research. Rather, it appears that major research effort on potassium in India should continue along current lines with ICAR, Potash Research Institute, Potash-Phosphate Institute of Canada and International Potash Institute coordinating their efforts to make a rapid headway to brighten the picture on current status of potassium fertility in Indian soils. This should outline soil and crop situations where potassium deficiencies are developing faster than others. It will be most rewarding to make a judicious choice of the benchmark soils for monitoring of potassium fertility changes and crop response to fertilizers. Soils where decline in plant available potassium sets in early, ought to receive priority for monitoring. Areas that currently produce high crop yields, generally with adequate water management and fertilizer application fall in this category. Soil which currently produce modest yields, perhaps owing to inadequacies of water and/or nutrients but are expected to raise bigger crops in the immediate future should be in the second category. The benchmark soils must be carefully located on the basis of pedological classification.

There ought to be refinements in delineating potassium deficient soils. The critical limits which distinguish soils that are likely to profit from a supplementary application of potassium from those which are not, are currently uniform for all soils. The differences, in mineralogy and forms of potassium provide strong indications regarding desirability of different sets of critical limits. Research should be able to propose and test the most appropriate sets of such limits.

A benchmark soil shows a central tendency with respect to amount of available potassium but does exhibit considerable variation among adjacent fields in the same habitation. Understanding the variation in terms of particle size distribution and mineralogy should be rewarding. Similarly, samples of soils from distantly located areas, having different mineralogy (kaolinitic, montmorillonitic and illitic) but with similar amounts of exchangeable or exchangeable and water soluble potassium should be subjected to a detailed mineralogical investigation. Soils which rapidly deplete in available potassium should also be investigated.

Critical levels for appraising potassium deficiency in plants can differ in case of simultaneous deficiency of sulphur or zinc. Normally when a soil is sufficient in all nutrients other than potassium, critical level of potassium in the plants is relatively less than when the soil is simultaneously deficient in another nutrient. Series of studies should be planned to arrive at appropriate sets of diagnostic levels.

Research on priority basis is needed on potassium and water economy in crops. The thrusts should be to identify the soil which although according to the current limits of soil test are considered sufficient in supply of native potassium. Very likely, such soils will form a small fraction, say about 10 percent, of the sufficiency of block but will add upto a respectable area.

There is need to encourage work on the role of potassium in inducing pest resistance. Fruitful lines of investigation should be followed at 3-4 institutions where work should be done by a multi-disciplinary team. Like rainfed soils, need for extra potassium to counter the pest menace will have to be linked to the prevailing status of native potassium. A proportion of marginally sufficient-K soils may be found to profit from supplementary application of potassium.

It should be useful to develop potassium balance sheets for all typical soils. This will need adequate data on the gross and net contribution from irrigation water, crop residues, organic manures and removals through run-off and erosion etc. Soils most off-balance, should receive particular attention for studies on potassium needs of various crops.

Studies on surface charge characteristics of soils and release dynamics covering thermodynamic and kinetic aspects of lattice potassium of different clay fractions in major soil groups should be encouraged.

Concerns about sustainable farming should be visualized in the framework of doing conservation farming on degraded lands and concentrating crop production on lands that have no such problem. The results of Maximum Economic yield research should be useful for the latter category of soils, which form one-third to one-half of the cultivated area and are the most productive of the lot.

In conclusion, it should be recognized that there was a substantial increase in potassium research capacity in India during the fifties, sixties, eighties and nineties such that now the overall capacity of national research effort is considerable. The state agricultural universities have expanded their research capacity, leading to a horizontal spread of research. However, much of the energy and resources are being frittered in doing work which is often repetitions and commonly arises from poorly representative and inadequate sampling sites. Ideally, a concentrated national effort to generate yield increasing and quality improving technology could be served by an organized approach that would harness and wherever necessary expand available national research capacity. A simplified design of such an approach would imply putting in place a national mechanism for establishing priorities based on a common consensus of the importance of any proposed research. Thanks to the National Bureau of Soil Survey & Land Use Planning, Nagpur, basic pedological information is available for about nearly 200 soil series. It should be rewarding to develop a concerted plan of action with the participation of ICAR, PRII, PPIC, IPI and SAU's and collect meaningful information on potassium in soils and their developing needs for fertilizer potassium so that better informed decisions for farm advisory work can be taken up in the future when potassium deficiencies in soils will increasingly surface.