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Importance and management of potassium in crop production under the Indian context

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Introduction

Potassium (K) is an essential nutrient for plants. Plants uptake large quantities of K for various physiological processes like synthesis of essential biomolecules (e.g., starch, cellulose, vitamins, proteins) and numerous enzyme activation. Potassium helps to regulate opening and closing of stomata and hence provides drought resistance to plants. Potassium also helps to develop resistance to other abiotic and biotic stresses and improves the produce-quality in crops. Potassium helps in better utilization of nitrogen (N) and phosphorus (P) by crops.

A plant facing K deficiency may not immediately show characteristic visual symptoms at first. The K deficiency may cause poor growth rate in the initial stages. If K deficiency persists, visual deficiency symptoms appear. Being mobile inside plants, K deficiency symptoms first appear on the older leaves or the leaves in the lower part of the plant. However, K deficiency symptoms may sometimes be seen on young leaves of high-yielding crops which are maturing very fast, e.g., cotton. Due to K deficiency, leaf tips and margins turn yellow (become chlorotic) and the die (become necrotic), and reveals a burnt up look on the leaf edges. The K deficiency may also manifest itself in some legume and forage crops as small white coloured necrotic spots forming an inimitable pattern along the leaf margins. Salinity may also produce necrosis in leaf margins, however, it does so initially on the new leaves unlike K. In addition, K-deficiency is likely to weaken the straw, and increase the probability of lodging in small grain crops, and drastically reduce yields. Moreover, K-deficiency can increase the chances of pest and disease infestation in crops. Deficiency of K may also reduce the shelf-life and storability of agricultural produce. Besides its functions in plants, K is present in several important soil mineral structure. Hence, K is crucial for soil health as well as crop productivity.

Crops generally require K in amounts similar to that of N. Notwithstanding, K fertilization is nil or inadequate in most of the intensively cultivated lands of India due to several reasons pointed out by Das et al. (2022). The provisional N: P_2O_5: K_2O consumption ratio in 2021-22 was 7.7: 3.1: 1 in India, and it has remained tilted towards N and P (more towards N between N and P) for decades (FAI 2022). No or inadequate K fertilization combined with removal of crop residues from the field after harvest cause severe K depletion in crop-fields, which deteriorates soil fertility and endangers the sustainability of crop production systems. It is imperative to apply ample amount of K for crop production. For proper management of the K in crop production, one has to keep in mind the available sources of K, and the time and method of application as discussed hereunder:

Potassium sources for crop production

Chemical fertilizers: The most common fertilizer sources of K are muriate of potash (MoP), which contains 60% K_2O or 50% K, and sulphate of potash (SoP), which contains 50% K_2O or 41.66% K. As these fertilizers contain water-soluble compounds (potassium chloride in MoP and potassium sulphate in SoP), the K supplied through them becomes immediately available for plant uptake. At the same time if applied in light textured soils with low organic matter before an irrigation or a heavy rainfall, a large amount of K from these water-soluble fertilizers may be leached down. The SoP is generally advantageous for oilseeds, potato, tobacco, vegetables and fruit crops as it supplies sulphate (SO_4^{2-}) instead of chloride (Cl^-).

Though K-fertilizers are a convenient K-source for field application, they are costly as India is completely dependent on imports for the same. Moreover, global mineral reserves of K required for K-fertilizer manufacturing are wearing out fast due to the growing need generated by intensive cropping and unceasing introduction of high-yielding varieties that need more nutrients to attain yield potential than its predecessors. So, we have to look beyond fertilizers and explore the indigenously available unconventional K-sources for their ability to cater plants' K needs, e.g., K minerals available in India, crop residues generated in the field, manures and composts made from various agricultural by-products, K solubilizing microbes, etc.

Crop residues: Crop residues are often removed from the field after harvest, which aggravates the problem of soil K depletion under intensive cultivation. The crop residues can act as a rich source of K if returned to the field either through retention (essentially followed in conservation agriculture) or incorporation. There are several crop residues which contain at least 1% K, e.g., rice straw, wheat straw, oat straw, sugarcane bagasse, etc. Stems of tobacco can contain as high as 7% K (Das et al. 2022). The residues amount to 50-70% of the total biomass of an annual crop. Hence, a significant portion of the K taken up by the crop from the soil can be returned back after the crop harvest through retention or incorporation of the residues. However, as the residues might take long time to decompose and release the nutrients they contain, the benefits of returning residues to supplement K nutrition of crops may not be reaped in short-term periods. Nonetheless, if applied with a basal dose of K fertilizer, the same may prove advantageous in reducing the K-fertilizer requirement and curbing soil K depletion. Besides direct return of crop residues as such, they may be made into manures or composts (by mixing with other organics followed by composting) and then applied to the fields as a rich organic source of multiple nutrients.

Organics: manures and composts: Organic manures and composts can have different contents of K and other nutrients depending on their raw material and preparation method. They can be a fairly well alternative source of K, besides enriching soil organic carbon and overall fertility upon application. For example, urban/rural composts (~ 0.5–2% K), farmyard manure or FYM (~ 0.5% K), oil cakes (~ 0.8–1.4% K), pig manure (~ 0.5–1.2% K), poultry manure (~ 1.5–3% K), fish meal (~ 1.5% K), night soil (~ 0.4% K), and several such organics can supplement K fertilizers and enhance soil fertility. The

K content of manures and composts can be improved to various extents by mixing natural minerals like mica, K-feldspars, poly-halite, etc. The K-solubilizing microbes can be added during preparation of the composts from organic sources and K-bearing minerals to increase the proportion of soluble K in the final product.

Potassium bearing minerals: Silicate rocks which have K-containing minerals in their structure can act as alternative K-sources if applied in the correct way. Phyllosilicates (containing ~5–10% K, or sometime even higher) like muscovite, biotite, phlogopite, glauconite; and tectosilicates (containing ~15–16% K), e.g., orthoclase, microcline are some of the K-rich silicate minerals for consideration as alternative source of K. The silicate rocks are almost insoluble or only sparingly soluble. Hence, if applied as such, they will release K extremely slowly and most probably will not be able to even slightly match the plant K need. If applied with K-solubilizing microbes or used in composting, the organic acids released by the microbes or during composting will cause faster release of K from the structural moity of these minerals and will enhance their value as an alternative K source. Despite the fact that K-rich minerals are only little effective compared with fertilizers like MoP, SoP over short-term, they may prove beneficial in the long run, mostly in the intensely weathered acid soils susceptible to leaching. Low-grade K-minerals available in the country may be good alternative K source in highly weathered soils like Alfisols, Ultisols and Oxisols. Minerals like glauconite-rich green sand present in natural deposits in different parts of India, waste mica generated as a by-product of electrical industry can be viable minerals sources of K in India. With necessary chemical or biological modifications, waste mica becomes an effective K source in agriculture, especially in acid soils with low K reserve.

Apart from silicates, a mineral named poly-halite ($K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$) obtained from sedimentary marine evaporates can act as a rich source of K besides supplying Ca, Mg and S. It contains ~ 12% K apart from ~ 19% S, ~ 12% Ca, and ~ 6% Mg (Sirius Minerals 2016). Being a source of S, it is particularly beneficial for oilseed crops like mustard, or vegetables like cabbage and cauliflower. India also has a huge reserve of this mineral according to an estimate.

Potassium solubilizing bacteria: Potassium solubilizing bacteria (KSB) have the capacity to enhance the release of insoluble K by forming complexes and facilitating exchange reactions with fixed K or structural pools. Various species under the genera *Burkholderia*, *Bacillus*, *Paenibacillus*, *Acidithiobacillus*, and *Pseudomonas* have demonstrated encouraging results in solubilizing inaccessible and slowly available K to fulfil the K requirements of crops. These bacteria can be applied either independently or in conjunction with a K source such as a K-bearing mineral to achieve desired outcomes. Generally, KSB application has a positive impact on crop yields and K uptake. However, in our view, applying KSB without an external K source like a K-bearing mineral could potentially harm soil health by dissolving or altering K-bearing minerals in the soil, leading to accelerated K-depletion under intensive cropping. Nonetheless, even when applied alongside an external K source, it remains uncertain whether solubilization is confined solely to the added K source.

When and how to apply?

The timing of K fertilization varies depending on the crop and site. Because K tends to stay in place in the soil, K fertilizers are typically incorporated during land preparation prior to sowing. However, the movement of K ions within the soil can be influenced by variables like soil cation exchange capacity (CEC), texture, type of clay, organic matter content, movement of water, etc. Recommendations for K fertilization consider multiple factors such as desired crop yield, soil K levels, climate, management practices, and growth stage. Frequent applications of small amounts of fertilizer can reduce luxury consumption of K in some plants, and potentially mitigate excessive leaching or fixation before plant uptake. Generally, K fertilizers are broadcasted and mixed into the surface soil, with band placement reserved for soils with low available K or high K-fixing capacity. Split applications may be considered in certain scenarios as an alternative to basal application. Certain crops like cotton, which have high K requirements, benefit from pre-plant soil applications or mid-season side-dressing. Choosing proper timing and method of K fertilization can enhance K use efficiency, particularly in systems that involve foliar spray or fertigation techniques. Fertigation, particularly through drip irrigation, can improve water and K use efficiency, though it is most suitable for high-value plantation crops such as fruit trees due to infrastructure constraints. Fertigation in fruit trees has shown comparable downward movement of K in the soil to broadcasting, with better lateral movement. Placement of K fertilizer at 8–10 cm depth can mitigate runoff losses in high rainfall areas, such as with the pocket method where fertilizer is placed in or around planting pockets. Band placement of K fertilizer is more effective than broadcasting in soils with high K-fixing capacity.

Epilogue

The intensively cultivated soils in India have been subject to continuous K extraction, leading to a depletion of K reserves over time. Prolonged K depletion can affect various soil K reserves, leading to detrimental effects on fertility and overall soil health. Additionally, prolonged soil K extraction can result in irreversible alterations to K-bearing minerals, posing a significant risk to agricultural sustainability. It is imperative to apply sufficient K inputs, either through commercial fertilizers or alternative sources such as crop residues, manures, and K-rich minerals, or a suitable combination thereof. These inputs should be applied at the appropriate time and using suitable methods to meet crop demands under intensive cultivation with the ultimate goal to sustain crop yields, preserve soil health, and thereby increase farm income over the long term.

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