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Importance of Different Potassium Forms in Crop Production

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Abstract
Potassium (K) is an essential plant nutrient for crops, grassland and livestock. Maintaining soil fertility to produce good crop yield requires the balance application of all plant nutrients including K. Potassium is a univalent cation that is found in the highest concentration in plant cell sap, earning it the nickname "master cation." In plants, K exists in its ionic form (K^+), remaining free (not bound to any constituent) and mobile. Mineral soils contain 0.04-3% potassium, meaning the total K in the top 0.2 meters of most agricultural soils typically ranges from 10 to 20 g/kg. However, the majority of soil K (92-98%) is incorporated into the crystal lattice structure of minerals, making it unavailable for direct plant uptake. To simplify the complex dynamics of K in soil, it is often classified into five groups based on its availability to plants. Water-soluble K is directly available to plants and microbes and is susceptible to leaching. Exchangeable K is electrostatically bound as an outer-sphere complex to the surfaces of clay minerals and humic substances. Both of these K fractions are considered easily available for crops, but their pool sizes are very small, making up only about 0.1-0.2% and 1-2% of the total soil K, respectively. Non-exchangeable and physically bound forms are considered slowly or non-available as K sources for plants, though they can significantly contribute to plant supply over the long term.

Keywords: Water-Soluble K, Available K, Exchangeable K, HNO_3-K, Lattice K, Total K Fractions; Nutrient Management etc.

Introduction
The growing global population has compelled us to increase food production despite limited natural resources. Developing countries like India, projected to have a population of approximately 1.67 billion by 2050, will require approximately 400 million tonnes (mt) of food grain. Unfortunately, the quality and availability of these natural resources are declining [1, 2]. Additionally, recent climate models predict that the frequency and duration of drought and heat stress periods are increasing in many regions, negatively affecting major crops and threatening food security. Therefore, a major challenge for agriculture is to enhance crop yields using more resource-efficient systems and to stabilize plant development and yield formation under biotic and abiotic stress conditions [10]. Furthermore, intensive agricultural practices can adversely affect microbial populations and disrupt the various cycles of plant nutrient availability in the soil. A promising solution involves applying both organic and inorganic sources of K in maize and chickpea cultivation, which has been shown to improve

the soil's overall plant nutrient status. Integrated Nutrient Management (INM) improves soil fertility, enhances crop yield, boosts soil microbial population and diversity, and mediates plant nutrient dynamics in the soil [4]. Potassium in soil behaves somewhat elusively: while the total K content in most soils is quite high, its availability is largely influenced by various soil and plant-related factors [3]. Among the many plant nutrients, K plays a particularly crucial role in several physiological processes vital to growth, yield, quality, and stress resistance of all crops [6]. [8]. Potassium constitutes about 2.1-2.3% of the Earth's crust, making it the seventh or eighth most abundant element. However, large agricultural areas worldwide are deficient in available K. Soils inherently low in K are often sandy, waterlogged, saline, or acidic. In intensive agricultural production systems, K has become a limiting element, especially in coarse-textured or organic soils [7]. Lower fertilizer K application, especially in the context of unbalanced fertilization, can lead to a significant depletion of available soil K reserves, thus decreasing soil fertility.

Role of Potassium in Plants

Potassium is crucial for creating the ionic environment needed for metabolic processes in the cytosol, acting as a regulator of various functions including growth regulation. Plants need potassium ions (K^+) for protein synthesis and the opening and closing of stomata, which is controlled by proton pumps that cause guard cells to become either turgid or flaccid. Potassium is essential for pH stabilization, enzyme activation, protein synthesis, stomata movement, cell extension, and photosynthesis. It plays a vital role in water relations (osmotic regulation), energy relations, the translocation of assimilates, photosynthesis, and the synthesis of proteins and starches. More than sixty enzymes in plants require K for activation. Besides its key role in metabolic processes and grain/seed yield formation, K enhances the quality of agricultural produce, prevents lodging in cereal crops, and increases resistance to pests, diseases, cold, and frost. Potassium significantly influences water regulation in plants, affecting both water uptake through roots and its loss through the stomata. It is also essential for every step of protein synthesis and activates the enzyme responsible for starch synthesis. Overall, K is vital for the activation of many growth-related enzymes in plants [5].

Determination of soil K fractions

Different K fractions in soil samples—namely water-soluble K, available K, exchangeable K, HNO_3-K, lattice K, and total K—were determined using standard methods. Water-soluble K was measured by shaking a soil-water suspension at a 1:2.5 ratio for half an hour. Available K was extracted using neutral normal ammonium acetate at a 1:5 soil-solution ratio, and the K in the extract was measured with a flame photometer. The exchangeable K fraction was calculated as the difference between available K and water-soluble K. The HNO_3-K was determined by the boiling nitric acid extraction method as described by Wood and Deturk. Total K content was measured by digesting soil samples with hydrofluoric acid (HF) in a closed vessel. Lattice K was calculated by subtracting HNO_3-K from total K.

Distribution of K forms

Potassium exists mainly in four forms: water-soluble K, exchangeable K, non-exchangeable (fixed) K, and lattice K. These fractions are in dynamic equilibrium with each other, which in turn governs K nutrition in crops. Regardless of treatments, the soil K fractions follow this order: *Total K > Lattice K >* HNO_3*-K > Available K > Exchangeable K > Water-soluble K* [3]. The nature of this equilibrium varies depending on soil type and the nature of clay minerals present. Readily available K, which constitutes only 1-2% of total K, exists in two forms: solution K and exchangeable K adsorbed on soil colloidal surfaces. These forms maintain a dynamic equilibrium with each other. Water-soluble K is the dominant fraction at the initial stages of crop growth, while exchangeable and non-exchangeable K contributes more in later stages. In increasing order of plant availability, soil K exists in these forms: mineral (5000-25000 mg/kg), non-exchangeable (50-750 mg/kg), exchangeable (40-600 mg/kg), and extractants (1-10 mg/kg).

Water Soluble K: Potassium availability in soil solution as a soluble cation is termed water-soluble K, which is readily absorbed by plants and relatively unbound by cation exchange forces, making it susceptible to leaching losses depending on soil properties. Water-soluble K constitutes approximately 10 percent of the available K. In Vertisol of central India, water-soluble K under various long-term Integrated Nutrient Management (INM) modules ranged from 3.71 to 8.75 mg/kg [3]. There was a further increase in water soluble-K under NPK +FYM amended plots over the NPK treated plot at all the soil depths. Such an increase in the content of water soluble-K might be due to addition of organic materials as reported earlier Sood *et al.* [10]. Similarly, Jadhao *et al.* [7] observed that water-soluble K increased significantly with higher doses of K and the addition of FYM.

Exchangeable K: Defining and determining the exchangeable-K of a soil is challenging both theoretically and experimentally due to the lack of a clear boundary between soluble and exchangeable fractions, as well as the presence of K that is not easily exchanged by typical reagents in some soils [3]. Exchangeable K refers to the form of K within the soil matrix that can be replaced by cations from neutral salts in the soil solution. Higher amount of water soluble and exchangeable K in surface layer may be attributed to the accumulation of K applied through the organic material and fertilizers. Similar distribution of water soluble and exchangeable K in surface and sub-surface horizon were also reported by Lakaria *et al.*, [8] & Srinivasa Rao *et al.* [11]. It constitutes approximately 90 percent of the available K, with the percentage of exchangeable K to total K typically below 2 percent.

Non-Exchangeable K: Non-exchangeable K comprises forms of K excluding water-soluble K and readily exchangeable K. While this form of K is not readily accessible to plants, it remains in equilibrium with available forms and thus serves as a crucial reservoir of slowly available K. Clay minerals possess the capacity to fix K; during soil wetting and drying cycles, K becomes trapped between the layers of these minerals. Upon soil wetting, some of the trapped K ions are released into the soil solution. Slowly available K is typically not measured in routine soil testing. Dotaniya *et al.* [3] suggested that the low values of non-exchangeable K in surface soils may result from the release of non-exchangeable K to compensate for the loss of available K due to crop uptake and leaching.

Lattice K: Lattice K represents the fraction of K that becomes fixed within the lattice spaces of 2:1 clay minerals. This component typically constitutes between 92 to 98 percent of the total K content in various soils, often indicating the richness of K-bearing minerals within the soil. The availability of lattice K to plants is facilitated through weathering processes, with the amount released dependent on soil texture and environmental conditions. Soils abundant in vermiculite and micas tend to possess larger amounts of nonexchangeable K, while those containing kaolinite, quartz, and other siliceous minerals typically contain lesser amounts of available and exchangeable K. The distribution of K forms within the soil and the equilibrium among them play pivotal roles in determining the K status of the soil and its potential for supplying K to plants. Various factors—such as clay mineralogy, texture, moisture levels, cation exchange capacity, pH, and concentrations of other soil ions—affect the physical, chemical, biological, and climatic equilibrium of K within the soil. Furthermore, soil management practices, including fertilization and cropping, significantly influence the equilibrium of K within soils. The quantities of plant-available and non-available K can vary widely among different soil types, with dynamic equilibrium reactions existing between the various pools of soil K [7]. Consequently, numerous soil physical and chemical properties, along with interactions between plants and soil, as well as microbial activities, collectively influence both the fixation and release of K within soils.

Total K: A significant portion of the total K in soil exists as a structural component of soil minerals, rendering it unavailable to plants. According to Sekhon (1999), the distribution of total K varies across different soil types, with illitic alluvial soils containing the highest amounts, followed by smectitic Vertisols, vertic intergrades, kaolinitic red soils, laterite soils, and kaolinitic acidic alluvial soils. The total K content in surface soils ranged from 0.77 to 1.59 percent. This form of K contributes the most to the total K content compared to other fractions, primarily because it includes K from K-bearing minerals. In an experiment evaluating various INM modules, it was found that the application of FYM at a rate of 20 tons per hectare per year in maize and 5 tons per hectare of FYM annually in chickpea resulted in the highest availability of K fractions in both years. This increase was attributed to higher yields and increased nutrient uptake due to intensive cropping in a long-term fertilizer experiment conducted in Madhya Pradesh [3]. Interestingly, despite the application of K fertilizer, the total K content remained almost unchanged. Additionally, it was observed that the addition of inorganic fertilizer and organic sources helped to minimize the K status in the Vertisol.

Epilogue: Potassium stands as a critical plant nutrient, pivotal in determining crop yield and seed quality. Despite this, many farmers tend to underestimate its significance in crop production. Present in soil in four forms—water-soluble K, directly absorbed by plants; exchangeable K, available to plants and held by negative charges on clay particles; fixed K, trapped within layers of expanding lattice clays; and lattice K, an inherent component of primary K-bearing minerals—K constitutes over 98% of the total K reserve in soil, predominantly in inorganic combinations. The importance of K in Indian agriculture has surged with the intensification of farming practices. Serving as an essential nutrient for all living organisms, including plants and animals, K is a univalent cation, with the highest concentration (100-200 *m*M) found in plant cell sap, earning it the moniker 'master cation'. Ionic (K^+) and free (not bound to any constituent), K demonstrates mobility within plants. Understanding the various forms of K and their distribution in soils aids in assessing long-term nutrient availability and facilitates prudent fertilizer recommendations for efficient crop production.

References

1. Dotaniya CK, Lakaria BL, Sharma Y, Meena BP, Aher SB, Shirale AO, *et al.* (2022) Performance of chickpea (*Cicer arietinum* L.) in maize-chickpea sequence under various integrated nutrient modules in a Vertisol of Central India. *PLOS ONE*, 17(2): e0262652.
2. Dotaniya CK, Lakaria BL, Sharma Y, Meena BP, Shirale AO, Dotaniya ML, *et al.* (2023) Estimation of potassium by Mehlich-3 extractant under integrated nutrient management. *National Academic Science Letter*, https://doi.org/doi10.1007/s40009-023-01282-3.
3. Dotaniya CK, Lakaria BL, Sharma Y, Meena BP, Wanjari RH, Shirale AO, *et al.* (2023) Potassium fractions in black soil mediated by integrated nutrient management modules under maize-chickpea cropping sequence. *PLoS ONE*, 18(9): e0292221.
4. Dotaniya CK, Lakaria BL, Singh M, Sharma Y, Meena BP, Dotaniya ML, *et al.* (2022) Long-term integrated nutrient management on potassium balance and uptake kinetics in maize–chickpea cropping system in a Vertisol. *The Pharma Innovation Journal*, 11(1): 1358–1362.
5. Dotaniya ML, Meena VD, Basak BB, Meena RS (2016) Potassium uptake by crops as well as microorganisms. In: Potassium solubilizing microorganisms for sustainable agriculture (Meena VS, Maurya BR, Verma JP, Meena RS, eds). *Springer India*, pp 267–280.

6. Goulding KWT, Stevens PA (1988) Potassium reserves in a forested, acid upland soil and the effect on them of clear-felling versus whole-tree harvesting. *Soil Use and Management*, 4(2): 45-51.
7. Jadhao SD, Dipali A, Mali DV, Singh M, Kharche VK, Wanjari RH, *et al.* (2018) Effect of long-term manuring and fertilization on depth wise distribution of potassium fractions under sorghum-wheat cropping sequence in vertisol. *Journal of Indian Society of Soil Science*, 66(2): 172–181.
8. Lakaria, B.L. and Singh, D. (1998) Crop yield and uptake of potassium by maize, wheat and cowpea (fodder) in relation to various potassium forms in soil under intensive cropping and continuous fertilizer use. *Indian Journal of Agricultural Sciences*, **68**(11): 734-735.
9. Römheld V, Kirkby EA (2010) Research on potassium in agriculture: needs and prospects. *Plant and Soil*, 335(1): 155-180.
10. Sood, Bannu, Subehia SK, Sharma SP. (2008) Potassium fractions in acid soil continuously fertilized with mineral fertilizers and amendments under maize-wheat cropping system. Journal of the Indian Society of Soil Science. 56:54-58.
11. Srinivasa Rao Ch, Kundu S, Ramachandrappa BK, Sharanbhoopal Reddy, Rattan Lal, Venkateswarlu B, *et al.* (2013) Potassium release characteristics, potassium balance and finger millet (*Eleusine coracana* G.) yield sustainability in a 27- year long experiment on an Alfisol in the semi-arid tropical India. Plant & Soil. 20-28.