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Potassium dynamics under different soil orders in India: A review

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ABSTRACT

Potassium plays a vital role in enzyme activation, water relations (osmotic regulation), energy relations, translocation of assimilates, photosynthesis, protein and starch synthesis. Potassium in soil exists in four principal forms -solution K, exchangeable K, non-exchangeable K and structural K; these forms are in a state of dynamic equilibrium. The vast quantity of potassium is removed; 1.5 times more than nitrogen, and Potassium application is significantly lower than that of N or P. In practically all intensive cropping systems in India, the K balance is negative because the addition of K rarely matches its removal, leading in massive K mining. The long-term intensive cropping systems,without K inputs, unfavourably affect K supply for plant uptake, ultimately hindering yield of the crops. In India, soil K fertility is measured using K extracted from neutral normal ammonium acetate but non exchangeable K release with boiling 1M HNO 3 has been noticed to be a better approach for categorising soils for K availability to plants because it offers some useful information on the K-supplying capacity of the soils under continuous cropping systems. The availability of potassium is determined by the overall content, the release properties of its various forms, the presence of clay minerals in varied proportions, and the particle size fractions. Measuring soil K fractions is insufficient for assessing long-term soil K fertility changes; one must also investigate the release properties of native K in terms of Q/I parameters, threshold values, and release kinetics.

Key words: *Potassium Fractions, Potassium fraction behaviour, Potassium fixation, Soil orders.*

Introduction

K is one of the most plentiful elements in the Earth's crust, making up around 2.1-2.3% of it (Zorb *et al.*, 2014). Potassium is often regarded as being abundant in Indian soils. According to reports, the range of potassium in benchmarks Indian soils is 0.35 to 4.65%. (Sekhon *et al.*, 1992). One of the three major plant nutrients for all living things, including plants and animals, potassium is the seventh most nutrient-dense element in the earth's crust. With agricultural intensification, its significance in Indian agriculture has grown. It is a univalent cation that is called a "master cation" because plant cell sap contains the highest concentration of it. The symbol for potassium, K, is derived from the German word kalium. In the Colonial era, individuals would burn organic materials and wood in pots to create soap. After rinsing the ashes, the remaining water would evaporate, leaving behind potassium salts. This substance was referred to as "potash" or "pot ashes." People would then boil these salts with animal fat to create soap. A botanist named Samuel William Jackson conducted an analysis of plant ash after burning them in Connecticut in 1868. Jackson discovered that plants contained significant amounts of potassium and other minerals. His work resulted in the development of fertilizers to increase crop yields

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(McAfee, 2008).

In plants, potassium is ionic (K+), free (not attached to any other ingredient), and mobile. According to Mengel and Krikby (1987), potassium is essential for the activation of enzymes, osmotic management of water, energy relationships, assimilate translocation, photosynthesis, protein, and starch production. K is required for the activation of over sixty enzymes. For crop productivity, potassium is frequently regarded as the quality element (Usherwood, 1985), and it is acknowledged as a quality-plus yield nutrient. The primary function of K is stomatal opening and closure, which maintains water transpiration and atmospheric CO_2 penetration into leaves, both of which contribute to increased water usage efficiency (Mengel and Forster, 1973).

The sustainable management of soil potassium has been given less attention in recent decades compared to nitrogen and phosphorus (Simonsson *et al.*, 2007). Although illitic clay minerals dominate our soils, making available potassium abundant, farmers tend to neglect the application of potassium fertilizers. Currently, the agricultural sector experiences a net negative balance of 19% for nitrogen, 12% for phosphorus, and 69% for potassium. The high proportion of potassium is due to crops removing on average 1.5 times more potassium than nitrogen, and the application of potassium fertilizer is considerably lower than that of nitrogen or phosphorus (Gurav *et al.*, 2018; Tandon, 2007). Most intensive cropping systems in India have a negative potassium balance, resulting in excessive mining of potassium since the addition of potassium rarely matches its removal. This situation puts pressure on non-exchangeable potassium to meet the potassium requirements of plants. Without potassium inputs, long-term intensive cropping systems unfavourably affect the supply of potassium to plants, ultimately leading to lower crop yields (Swarup, 1998). Therefore, it is crucial to consistently prioritize the role and importance of potassium in sustainable crop production through balanced nutrient management. To maintain soil fertility, the removal of potassium must be balanced by sufficient potassium inputs.

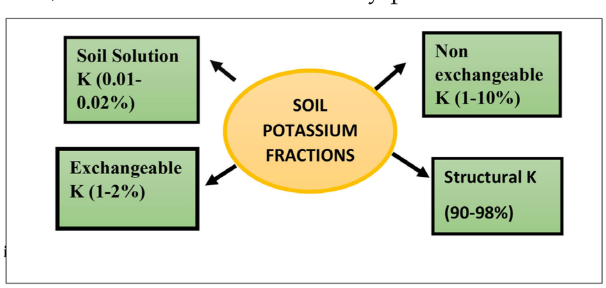

Fig. 1. Potassium fractions in soil.

Soil Supply of Potassium

Potassiumin soils

A basic comprehension of the fundamental process associated with the soil Potassium cycle is imperative to guarantee appropriate potassium nourishment of crop plants. In soils, potassium is present in diverse forms, such as water-soluble, interchangeable, non-interchangeable, and lattice potassium. The degree of K in soil solution and promptly accessible forms for plant uptake at any given time is affected by kinetic and equilibrium reactions between the four forms of soil K. The four K fractions, in the sequence of their availability to microbes and plants, are: solution > interchangeable > fixed > mineral K (Sparks, 2000). The abundance of different fractions and their release majority is reliant on the types of minerals in clay and silt fractions of a particular soil.

Water-soluble potassium

The K form is easily accessible to both plants and microorganisms. In typical agricultural soils located in moist climates, the quantity of potassium in the soil solution is between 2 to 5 mg K^{-1} (Haby *et al.*, 1990). The potassium amount primarily relies on the exhaustion and restoration of interchangeable and non-interchangeable types of potassium. Non-interchangeable K+ is discharged due to the reduced K content (Hay 1976) of the soil solution, which helps in enhancing the efficiency of water usage by absorbing water and ambient CO2 through the leaf (Mengel and Forster 1973).

Exchangeable K

Plants may readily access the form of potassium that is interchangeable with other cations.K is electrostatically bonded as an outer-sphere complexOn the surface of the clay minerals and humic compounds (Malavolta, 1985). Clay minerals' capacity to store K+ at exchange sites depends on both thermodynamic and kinetic variables (Parfitt 1992). The concentration and type of the soil surface of K+ in respect to the other exchangeable and primarily divalent cations present in the soils available to plants influence the affinity of the exchange sites for K+ (Barré *et al.*, 2008). It can be exchanged for other cations, and plants can readily access it (Barré *et al.*, 2008).

Non-exchangeable K

It is trapped inside the clay mineral layers and is not readily available for exchange with other cations. It is kept in place by vermiculites, intergrade clay minerals, such as chloritized vermiculite, and neighbouring tetrahedral layers of dioctahedral and trioctahedral micas (Sparks, 1987; Sparks *et al.*, 1985). Potassium is fixed because the forces that hold potassium to clay surfaces are stronger than the forces that keep individual K+ ions hydrated. They cause the crystal formations to partially collapse.

K+ ions are physically confined, making K release a gradual, diffusion-controlled process. Throughout a single growth season, developing plants cannot utilise much of the slowly available K. Slowly available K can act as a storage space for easily accessible K.

Structural K

Structural K, also referred to as mineral K, is covalently bound within the crystal structure of K-containing minerals such as feldspars and micas (Metson, 1969). It is commonly believed that plants can only access structural K at a slow rate, but its availability is influenced by the amount of K present in other forms and the extent of weathering of the micas and feldspars that make up the mineral K fraction (Sparks, 1987 and Sparks *et al*., 1985).

Importance of non-exchangeable Potassium in Plant Nutrition

In India, the quantity of K extracted with neutral normal ammonium acetate is utilized to assess the soil's K fertility (NH4OAc). However this extractant has frequently failed to reveal crop-induced changes in soil K. (Velayutham *et al*., 1985; Singh *et al*., 2017). In the utter lack of an optimal K supply in many crops, several researchers (Mengell, 1985) have reported that a sizeable portion of K (70–90%) needed by plants comes from the non-exchangeable pool, demonstrating the usefulness of fixed K. K(nx) contribution becomes more significant in soils with low NH4OAc-K levels (Dhar and Sanyal, 2000; Ghorban 2007). Non-exchangeable K (Knx), which is stored on the edge, wedge, and inter layers of soil clay minerals, meets an important part of the crop's nutritional needs. When soil solution and exchangeable K levels are lowered by plant uptake and leaching, the non-exchangeable K fraction is liberated (Martin and Sparks, 1983). The amount of intermediate-K found in the wedge and edge zones of micaceous minerals (Beckett, 1971). Below a specific critical value of K concentration in soil solution, referred to as threshold concentration, this intermediate K is liberated in the soil solution (Datta and Sastry, 1989). Consequently, knowledge of the threshold level of soil exchangeable K at which NEK release starts is essential in figuring out the K store of soils and its accessibility to plants.

Since repetition extractions with boiling 1.0MHNO3 provide some valuable information on the K-supplying potential of the soils under ongoing cropping systems, it has been determined that non-exchangeable K discharge with boiling 1MHNO3 is a more appropriate method to classify soils for K accessibility to crops.There was a strong association between boiling 1.0MHNO3-extractable K and crop uptake and reaction to K. Step K and constant-rate K (CR-K) are notions that Haylock (1956) established as indicators of plant-utilizable, non-exchangeable K release in soil. Step K is the potassium release with repeated 1.0 N HNO3 extractions and constant rate -K, which is the rate attained when the potassium release with each extraction is equal to the preceding one.Metson (1969) discovered that CR-K serves as an empirical guide to the long-term K providing capacity of soils and takes into account soil type and mineralogy. According to several studies, the non-exchangeable form of potassium (NEK), which is initially unavailable to growing crops, significantly contributes to the nutrient needs of plants (Tiwari 1985; Ganeshamurthy and Biswas 1985; and Santhy *et al.,* 1998). Regarding K nutrition, it is crucial to understand the characteristics of the soil's K reserve and its release pattern. The source of the nutrient that is currently available to crops is thought to be the labile pool of K in soils (the water-soluble and exchangeable K). When crops are planted one after another without using K, the soil's available pool of K is always under stress (Ganeshamurthy and Biswas, 1985) reported that during extended durations of investigation, there was a noticeable reduction in the amount of NEK to meet K requirement. According to Rupa *et al.* (2001), the soils with continuous cropping that did not get K fertiliser saw the largest loss of NEK stores.

Exhaustive cropping has been effectively used in the past by a number of researchers to better understand the release features of K reserve and its availability to crops (Mehta, 1976 and Brar and Sekhon, 1977). Since optimal exploitation of native soil K in the presence of sufficient fertiliser K is necessary for sustained agricultural production and soil health, it is crucial to conduct a systematic analysis of the distribution of various soil K forms, their relative abilities, and the soil's ability to support subsequent crops without the addition of extraneous K supply. A prior understanding of the soil's inherent ability to give K to the plant in the form of exchangeable and accessible pools of solution is necessary for the wise use of fertiliser potassium (K).

The NEK buffer in soils can be viewed as a measure of the soils' long-term capacity to supply K due to its slow release into the plant's pool of accessible materials. Continuous cultivation without K or with insufficient K fertiliser may significantly deplete the NEK soil reserve. Soil K status changes and crop response patterns to applied K must be continuously monitored.

Absorptionsites of potassium

There are multiple kinds of K+ adsorption sites on clay minerals (Figure 2). The K+ selectivity of those on flat surfaces (p-position) on the outer surfaces is low, but that of those on the edge (e-position) and wedge (w-position) is medium. Fixed K+ is the K+ found in the interlayer wedge and edge positions (Figure 1).

Different potassium fractions are in a dynamic equilibrium, and as K is depleted from one pool to another, it is refilled from other pools. The pace of replenishment could not be quick enough, though, depending on the situation, to meet the crop's demands. The overall content and release traits from its various forms, which are determined by the soil parameters, determine the availability of potassium in soil. In addition, vegetation and physiography have an impact on the availability of potassium to plants through their effects on drainage, runoff, leaching, erosion, and vegetation.

The composition and quantity of soil minerals, as well as the pedogenic processes taking place in the soil, greatly influence the behaviour of soil potassium with regard to other plant nutrients, fixation, release characteristics, and its absorption and response pattern. Heterogeneous composition, release, and K fixation behaviour in soil are caused by the presence of these minerals in varying concentrations and in diverse percentages of particle size at variable weathering stages. Because of the weathering of minerals like biotite, muscovite, orthoclase, and microcline, among others, soil naturally contains potassium (Rich, 1972).

For better K management of soils, soil order and series differences on soil K reserves need to be evaluated. The majority of soils have high levels of total K but only modest levels of K that is readily available. The majority of potassium is present as a component of many minerals, which weather at widely varying rates to release K into soluble and exchangeable forms (Huang, 1977).

Mineralogical composition on release and K fixation behavior in soil

According to a study by Sarkar *et al.* (2013), illite and kaolinite were the two minerals that were most abundant in the clay fractions of the Entisols

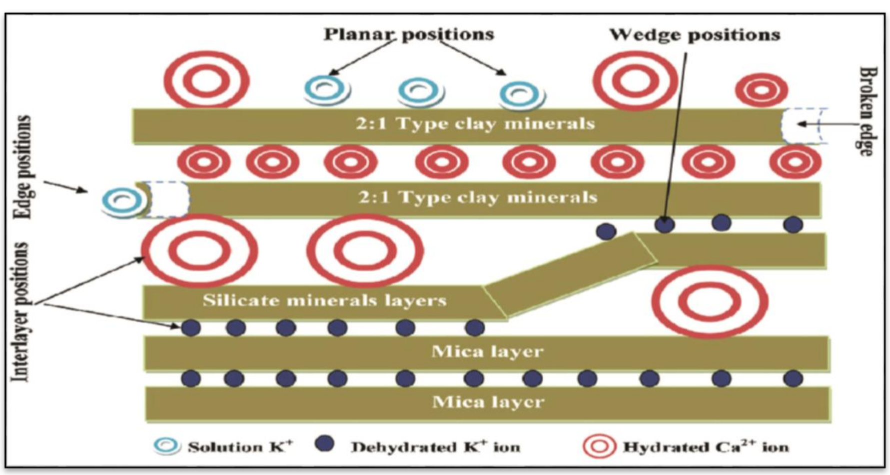

Fig. 2. Potassium adsorption positions for K+ in a mica–silicate mineral in the soil system [after Rich (1968)c.f, Mengel and Kirkby (1987)

Table 2. Semi-quantitative composition (percentage) of clay fraction of soils in different soil orders of West Bengal.

Soil Order	Smectite	Cholrite	Vermiculite	Interstratified	illite	Kaolinite
Entisol	9	28	-	-	53	10
Inceptisol	7	13	10	-	55	15
Alfisol(1)	-	-	-	-	39	61
Alfisol (2)	10	-	8	-	31	51

Sources: Ghosh and Debnath, (2010)

(Garubathan soil) and Inceptisols (Ranaghat, Sonakhali, Gosaba, and Hatighisa soil) in the West Bengal region. In the soils of Polba and Md. Bazar (both soils fall under the order of Alfisols), kaolinite predominates following by illite, whereas in the soil of Ranibundh (Alfisols), illite predominates followed by kaolinite. The type of clay mineral and its charge density, the interlayering level, the moisture levels, the proportion of K+ ions in addition to the concentration of competing cations, and the pH of the ambient solution soaking the clay or soil all affect how much K is fixed in them (Rich 1968; Sparks and Huang, 1985).

Sarkar *et al.* (2014) conducted a study in two different soil order of West Bengal and recorded that the relative dominance of clay minerals in the clay fraction of the inceptisol is illite (44%) and whereas Ranibundh soil is rice in Kaolinite soil (28%) Another study by Srinivasarao *et al.* (2008) revealed that Mean total K levels in inceptisols that were greater than Aridisols. Following Vertisols in order of exchangeable K were Inceptisols, Alfisols, and Aridisols. Decreased non-exchangeable K in Alfisols may be caused by K-feldspar, which makes up a large fraction of total K and is very resistant and does not dissolve in boiling 1 N HNO_3. Vertisols showed greatest exchangeable K followed by Inceptisols, Alfisols and Aridisols. Lower non-exchangeable K in Alfisols could be due to presence of major portion of total K in the form of K-feldspar which are highly resistance and is not dissolve in boiling 1 N HNO_3. Decreased the content of non-exchangeable K in Alfisols may be caused by K-feldspar, which makes up a large fraction of total K and is very resistant and does not dissolve in boiling 1 N HNO_3.

Changes in different forms of potassium without and with fertilization of potassium in different soil orders

A study was conducted by Sarkar et al (2013) to see the release pattern of non-exchangeable potassium reserve in Alfisol, Inceptisol and entisol of West Bengal, India.) recorded that From the above Sonakhali soil showed much higher amounts of non-exchangeable K and Step-K, followed by Gosaba soil and Hatighisa soil, whereas Md. Bazar contained the least amount among the eight experimental soil

Table 6. Effect of intensive cropping (rice-rice) without addition of potassium fertilizer on distribution of different forms of potassium in soils after the first and the third cropping

Location	Forms of potassium C mol(p+) kg^{-1}					
	Stages of Cropping	Water Soluble K	Exchangeable K	Non exchangeable K (NER)	Step K	Constant rate
Ranibundh	Initial	0.051	0.205	6.76	7.76	0.32
	1st crop	0.044	0.176	6.43	7.17	0.30
	3rd crop	0.037	0.132	5.58	6.12	0.28
	SEM±	0.001	0.006	0.029	0.142	0.005
	CD(p=0.05)	0.004	0.019	0.087	0.429	0.015
Sonakhali	Initial	0.564	1.33	10.5	11.02	0.36
	1st crop	0.327	1.22	10.3	10.62	0.33
	3rd crop	0.305	0.960	8.98	9.50	0.30
	SEM±	0.024	0.033	0.141	0.134	0.006
	CD(p=0.05)	**0.074**	**0.099**	**0.428**	**0.405**	**0.018**

Sources: Sarkar *et al.* (2014

samples. The soils from Sonakhali, Gosaba, and Hatighisa were anticipated to release more K under stress condition efficiently. This may be because non-exchangeable K (NEK) or reserve K is an index of K availability under stress situation. The NEK of the soils in Md. Bazar and Polba indicates that long-term cropping on these soils may not provide sufficient K nutrition for crops.

Inceptisol and Alfisol were the subject of a study by Sarkar *et al.* (2014) on the depletion of soil potassium under exhaustive cropping. They observed that the soil variations in water-soluble K, exchangeable K, NEK, Step K, and CR-K after three rice crops. In Sonakhali soil, the percentage and net changes in the water-soluble K were more noticeable. All five types of K in both soils decreased with subsequent cropping. For Ranibundh soil, the decrease of water-soluble K was substantial at all phases of crop growth, but after the first and third crops, there was no difference in significance. This difference may be due to the release of NEK from the clay interlayer to the exchangeable and water-soluble forms. The Sonakhali soil's greater exchangeable and reserve pools of K than the Ranibundh soil may have sustained crop growth in the former without significantly affecting the soil.

In order to determine the effects of fertilization and manuring on the soil's ability to produce potassium, a field experiment was carried out after 45 rice-rice cycles from an ongoing long-term fertiliser experiment were completed at the ICAR-National Rice Research Center in Cuttack, India. Control (unfertilized), N (nitrogen fertilizer), NP (nitrogen plus phosphorus fertilizer), NK (nitrogen plus potassium fertilizer), NPK (nitrogen plus phosphorus and potassium fertilizer), FYM (farmyard manure), N + FYM, NP + FYM, NK + FYM, and NPK + FYM were the treatments. According to the results of this investigation, exchangeable K (Kex) varied amongst the treatments and ranged from 62.3 to 87.2 mg kg1. In comparison to the other treatments, the exchangeable K in NK +FYM was the largest l. With NPK + FYM, non-exchangeable K concentrations were highest (661 mg kg^{-1}), closely followed by NK (657 mg kg^{-1}) and NK + FYM (656 mg kg-^{1}) Despite significant crop absorption, continuous K fertilising and manuring kept Knx levels at such high levels. Even K-fertilized treatments failed to significantly outperform the control in terms of Knx. Knx was much lower in the NP treatment (577 mg kg^{-1}) than it was in the other treatments. This demonstrates how the soil's non exchangeable K reserve depletes when K is continuously withheld from the system even while the other two essential nutrients (i.e., N and P) are available in the fertilisation schedule.

Potassium release and Quantity and intensity relationship

As a metric of soil K fertility, the quantity-intensity (Q/I) relationship of soil K appears to be superior than NH4OAc-K (de la Horra *et al.*, 1998). The intensity, quantity, and buffering power notions put out by (Beckett 1964) can be used to define and quantify the soils' capacity to deliver potassium.

Solutions with increasing concentrations of KCl and decreasing concentrations of CaCl2 were used to equilibrate the provided soil sample. The quantity factor (Q factor) in the relationship is the amount of K that the soil gains or loses (K) during equilibration. As a metric of soil K fertility, the quantity-intensity (Q/I) relationship of soil K appears to be superior than NH4OAc-K. (de la Horra *et al.,* 1998). The intensity, quantity, and buffering power notions put out by (Beckett, 1964) can be used to define and quantify the soils' capacity to deliver potassium.

Solutions with increasing concentrations of KCl and decreasing concentrations of $CaCl_2$ were used to equilibrate the provided soil sample. The quantity factor (Q factor) in the relationship is the amount of K that the soil gains or loses (K) during equilibration. The amount of K in soil solution that is instantly accessible for plant roots to absorb. The potassium activity ratio is utilised to show the intensity factor since this K absorption is impacted by the activity of other cations like Ca^{2+} and Mg^{2+} in the soil solution.

ARek=K^+ /"Ca^2+ Mg^{2+} where 'a' is the activity of the respective ions in the equilibrium solution.

The quantity factor (Q) is the measure of capacity of the soil to maintain the level of K in soil solution (I) over a longer period or crop duration. The capacity is mainly due to exchangeable K, although non exchangeable K is released to meet the considerable of the crop needs.

Potassium release pattern, Threshold levels and Q/I parameters of different Soil orders

A study was done to determine the pattern of non-exchangeable potassium reserve release in the West Bengal, India, soil types Alfisol, Inceptisol, and Entisol. Sarkar and other (2013) presents straightforward linear equations that best describe the cumulative NEK release across all soils analysed. The release of cumulative NEK had a highly significant correlation coefficient and a semi-logarithmic behavior with an increasing number of extractions. This shows that as the number of extractions increased, the release of NEK reduced. Once more, Ghosh and Debnath (2010) conducted a study to determine the depletion of soil potassium under exhaustive cropping in inceptisol and alfisol and found that after each cropping, there was a significant drop in ARK e for these soils, which was clearly caused by the crop removal of exchangeable K in the absence of extraneous addition of K. With each additional cropping, the difference in ARK e values between the initial stage (before to cropping) and the following the first, second, and third crops of rice grew increasingly larger in all the soils. The threshold levels for intermediate K release, which closely matches to step-contents K's (Arnold and Close 1961; De *et al.*, 1993).

Again citing Sarkar *et al.* (2014), crop removal of exchangeable K under no extraneous K in the absence of K dissipation through other pathways caused a general decline in ARK e values for both soils on cropping. This considerable decrease in ARKe values during the course of repeated cropping was in line with earlier findings by Beckett and Nafady (1967a, 1967b); Abdel-Hamid (1992); and Dhar (1999). Several variables, including total labile pool of K (KL), held K (KX), and labile K (K0), also declined significantly in both soils. Similar findings were made by (Debnath, 1995; Dhar, 1999). Further Sarkar *et al.* (2014) stated that in both soils (Ranibundh and Sonakhali, West Bengal) the threshold levels for the release of intermediate K in terms of activity ratio, exchangeable K, and K concentration in soil solution showed a decrease after the third cropping as compared to the initial status .

According to Das *et al.* (2018), the Q/I plot for each treatment showed a curvilinear portion at low activity ratios indicating exchange at sites with greater affinity for K than Ca + Mg and a linear portion at high intensity levels describing the exchange behaviour of K and Ca + Mg at sites not having preferential affinity for K.The state of immediately accessible K in soil is indicated by the ARKe. Significant differences in ARKe were seen after long-term cropping with or without K addition by fertiliser or manure. The highest ARKe across all treatments was reported by NK + FYM (43.7 104 [mol L1]0.5), which was significantly higher than the lowest ARKe among the manure-added treatments by NP + FYM. The KL is a rough measure of the total content of labile K in a soil that can take part in ion exchange with Ca + Mg during the time period provided for equilibration. The treatments receiving K fertiliser, with or without FYM, had much higher K_0 than NP, the fertilisation strategy with the greatest imbalance in terms of K.The Potential Buffering Capacity of K measures the soil's capacity to sustain a specific level of K in the soil solution.

An experiment was conducted in various soil series of Vertisol of Dewas district of Malwa region, Madhya Pradesh to assess potassium fixation capacity and potassium release pattern by Gandhi *et al.* (2018). The amount of K extracted by stepwise extraction with 0.01 N HCl and the cumulative K releasing power of soils. The findings showed that there was a considerable variance in the K releasing power among the various soil series. From the first extraction to the thirteenth extraction, the amount of K extracted from the soils typically declined steadily until the majority of the soils released little to no K. The initial extraction had the highest K release from the Kamliakheri series (119 ppm) and the lowest K release from the Gabapura series (84 ppm). The soils of the Kamliakheri family, which have fine textures, high exchangeable K concentrations, and K saturation at the edge positions, may have held K with reduced tenacity and bondage, causing K release to occur quickly. Also during the second extraction, the Sarol series was followed by the Kamlikheri series in terms of the large magnitude (92 ppm) emission of K (87 ppm). The values of total step-K varied from 433 to 197 ppm. This indicated that the more the amount of step-K more will be the plant utilizable non-exchangeable K from micaceous minerals under K stress situation.

K fixation

As soluble K is added, it is transformed into a form that cannot be removed using a neutral salt solution, which reduces the availability of added K. K fixation is a significant process in the dynamics of soil K and it impacts the availability of K to plants. K fixation is the term used to describe the trapping of K+ in layers of 2:1 clays, primarily hydrous mica. K is small enough to reach the interlayer regions, where electrostatic forces firmly hold it. Regarding the soil's ability to supply K, the fixation of additional K is particularly crucial because K-depleted soils may fix a lot of it, making it momentarily unavailable to the plants. The fixed K slowly becomes accessible over time (Mengel and Kirkby 1980). So, understanding the soil's ability to fix K during long-term fertilisation and manuring is crucial for improving K management in cultivated soils. For potential improvements to the fertiliser K recommendation and modelling the transformation of fertiliser K in soils, potassium-fixation characteristics of soils are required (Sparks and Huang, 1985).

In an experiment on the ability of representative soils in the sub-montane zone of Maharastra to fix potassium and release it, Annapurna *et al.* (2017) found that Bamburi Series from Inceptisol had a higher fixation capacity than Sathesai Series from N.A.R.P., Kolhapur (91.80 mg kg-1) and Kurkum Series from A.C Farm, Kolhapur (99.10 mg kg-1). This may be because there are variations in the overall amount and kind of clays' K-fixing minerals.

Das *et al.* (2018) found that the K fertilised treatments considerably excelled the control, N, and NP in another lengthy fertiliser trial (Fig. 7). Due to significant depletions in the native K pool of the soil under conditions of optimal N supply or N and P without additional K, the Kf was lowest under N and NP (113 mg kg1). Kf under NPK in the treatments with inorganic fertiliser was substantially greater than control, N, and NP. In 45 years of rice-rice cropping system, Kf of NPK + FYM was considerably higher than FYM, N + FYM, and NP + FYM among the manure-added treatments.

Conclusion

- There are four important forms of potassium: solution, exchangeable, non-exchangeable, and structural. All of these forms are in a state of complicated and dynamic equilibrium.
- However, non-exchangeable K release with boiling 1MHNO_3 has been found to be a more appropriate method to categorise soils for K availability to crops as it offers some valuable knowledge on the K-supplying capacity of the soils under continuous cropping systems. In India, soil K fertility is assessed based on the amount of K extracted by neutral normal ammonium acetate (NH_4OAc).
- The NEK reserve in soils can be considered to be an indicator of the soils' long-term capacity to supply K due to its slow release into the plant's pool of accessible materials. Continuous cultivation without K or with insufficient K fertiliser may significantly deplete the NEK soil reserve.
- A better knowledge of exchangeable K release into soil solution and subsequent plant uptake is provided by quantity/intensity Q/I parameters.
- Different content, release, and K fixation behaviour in soil is caused by the presence of clay minerals (illite, vermiculite, montmorilonite) in distinct quantities and in diverse particle size fractions at variable weathering stages.
- In comparison to the Alfisols, the Entisol and the Inceptisol displayed a larger level of step-K, indicating a greater reserve for K release from originally non-exchangeable forms under K stress. Alfisols rich in kaolinite require more frequent K fertilisation during long-term cropping than Inceptisol and Entisols, which are dominated by illite.
- Measuring the soil K fractions is not sufficient to accurately assess long-term soil K fertility changes; one must also consider the release characteristics of native K in terms of Q/I parameters, threshold values and release kinetics, and fixation of added K.

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