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Relationship between potassium fractions and physico-chemical properties of soil under long-term fertilizer management in a soybean-safflower cropping sequence

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ABSTRACT

Potassium is a vital nutrient for plant growth, and its availability is governed by the balance between various potassium fractions in soil. The current investigation was undertaken to assess the relationship of different forms of potassium and certain physico-chemical properties of soil under a long-term fertilizer experiment in a soybean-safflower cropping sequence in Vertisols. The experiment was conducted during 2025-2026 at Research Farm of AICRP on long-term fertilizer experiment, VNMKV, Parbhani, comprised of different organic and inorganic treatments with randomized block design viz. T1-50% NPK, T2-100% NPK, T3-150% NPK, T4-100% NPK + hand weeding, T5-100% NPK + Zn, T6-100% NP, T7-100% N, T8-100% NPK + FYM @ 5 t ha⁻¹, T9-100% NPK - S, T10-FYM @ 10 t ha⁻¹, T11-absolute control and T12-fallow. The result emerged out from experimental findings showed that different forms of potassium was higher at 0-15 cm depth than 15-30 cm depth of soil in experimental site. Application of 100% NPK + FYM @ 5 t ha⁻¹ recorded all fractions of k significantly maximum than all other fractions whereas lower k fractions was observed in absolute control followed by fallow treatment. Correlation analysis was used to assess their relationships with selected soil properties. Organic carbon and available N, P, K and S showed significant positive correlations with all K fractions at both depths, whereas CaCO₃, EC, bulk density and porosity generally showed non-significant relationships. Particle density showed significant negative associations with selected K fractions, while pH showed a significant negative correlation with exchangeable K. The findings indicated that integrated application of NPK and FYM favoured the maintenance of higher soil K status and was closely associated with improved soil fertility under the soybean-safflower cropping sequence.

Keywords: Potassium fractions, Soil physico-chemical properties, Soybean-safflower, Vertisol, Long-term fertilizer experiment

Introduction

Potassium (K) is an essential plant nutrient involved in enzyme activation, water regulation, photosynthesis, protein synthesis and stress tolerance (Mengel *et al.*, 1987; Epstein *et al.*, 2005) [2, 1]. Although soils contain large quantities of total K, only a small fraction is readily available to plants. Soil K occurs in different pools, including water-soluble, exchangeable, non-exchangeable and mineral forms, which are continuously interrelated through dynamic transformation processes (Sparks, 1987; Syers, 2003) [3, 4]. Water-soluble and exchangeable K constitute the readily available pools, whereas non-exchangeable and mineral K act as important reserve pools that can replenish the available forms when soil K is depleted.

Long-term cropping pattern and fertilizer management can alter the equilibrium among these K fractions through crop removal, fertilizer application and organic matter addition. Continuous crop removal may gradually reduce readily available K, while non-exchangeable K can contribute to replenishment of the available pool and k in soil. Therefore, studying different K fractions is important for understanding the long-term K-supplying capacity of soil (Jalali, 2007; Singh *et al.*, 2017) [5, 6]. The distribution and transformation of these K pools are influenced by several soil properties, including clay mineralogy, organic matter and other physical and chemical characteristics of soil. Similarly the soybean-safflower cropping sequence is important in the semi-arid regions of Marathwada. The contrasting rooting patterns and nutrient requirements of soybean and safflower may influence K uptake, recycling and distribution within the soil profile. Continuous cultivation under this cropping sequence may consequently affect the transformation and replenishment of different K pools through crop uptake, residue return and fertilizer management.

In Vertisols, the distribution and availability of K may be influenced by clay content, mineralogy, soil properties and nutrient management. Although Vertisols may contain substantial amounts of total K, the proportion of readily available K and the release of K from reserve pools may vary with soil characteristics and long-term management practices. Therefore, assessment of K fractions at different depths and their relation

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ship with soil physico-chemical properties can provide useful information on K dynamics, distribution and retention under long-term nutrient management.

Therefore, the present study was undertaken to assess the relationship of different potassium fractions with selected physico-chemical properties of soil under a long-term fertilizer experiment in a soybean-safflower cropping sequence.

Materials and methods

Experimental site and design

A field experiment was conducted during the *kharif* and *rabi* seasons of 2025-2026 at the All India Coordinated Research Project on Long-Term Fertilizer Experiment (AICRP-LTFE), Department of Soil Science and Agricultural Chemistry, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India. The experimental site is located at 19°16' N latitude and 76°47' E longitude, at an altitude of 347 m above mean sea level. The region has a semi-arid tropical climate. The experiment was conducted on Vertisol under a soybean (*Glycine max* L.)-safflower (*Carthamus tinctorius* L.) cropping sequence. The experiment was laid out in a Randomized Block Design (RBD) comprising twelve treatments with four replications.

Treatments and nutrient management

The experiment comprised twelve nutrient management treatments: T₁-50% NPK, T₂-100% NPK, T₃-150% NPK, T₄-100% NPK + hand weeding, T₅-100% NPK + Zn, T₆-100% NP, T₇-100% N, T₈-100% NPK + FYM @ 5 t ha⁻¹, T₉-100% NPK - S, T₁₀- FYM @ 10 t ha⁻¹, T₁₁-absolute control and T₁₂-fallow. Nitrogen, phosphorus, potassium and zinc were supplied through urea, single superphosphate (SSP), muriate of potash (MOP) and zinc sulphate, respectively. For T₉, DAP was used instead of SSP to avoid sulphur addition. Fertilizers were applied by drilling, while FYM was incorporated into the soil before sowing of the *kharif* crop.

Soil sampling and analysis

Plot-wise soil samples were collected after crop harvest from 0-15 and 15-30 cm depths. The samples were air-dried, ground, sieved and thoroughly mixed before laboratory analysis. Selected physical and chemical properties, including bulk density, particle density, porosity, pH, electrical conductivity, organic carbon, available N, P, K and S, were determined using standard procedures. Bulk density was determined by the core sampler/clod coating method (Piper, 1966) [7], Particle density by the pycnometer method (Das et al., 1997) [8], and porosity was calculated from bulk and particle density. Soil pH and electrical conductivity (EC) were determined in a 1:2.5 soil suspension using a digital pH meter and conductivity meter, respectively (Jackson, 1973) [9]. Organic carbon was estimated by the Walkley and Black method (Piper, 1966) [7]. Available nitrogen was determined by the alkaline permanganate method (Subbiah et al., 1956) [10], Available phosphorus by the Olsen method (Olsen et al., 1954) [11], and Available potassium by neutral 1 N ammonium acetate extraction followed by flame photometric determination (Piper, 1966) [7] and available S by the turbidimetric method using a spectrophotometer (Chopra et al., 1976) [12].

Different potassium fractions, viz. water-soluble, exchangeable, non-exchangeable, lattice and total K, were estimated using standard analytical procedures. Water-soluble K was determined by water extraction (Richards, 1954) [13], Exchangeable K by 1 N NH₄OAc extraction (Knudsen et al., 1982) [14], Non-exchangeable K by 1 N boiling HNO₃ extraction (Wood et al., 1941) [15], and Total K by acid digestion followed by flame photometric determination (Jackson, 1973) [9]. Lattice K was calculated from the difference between total K and the sum of the other measured K fractions.

Statistical analysis

The relationship between different potassium fractions and selected physico-chemical properties of soil was assessed using correlation coefficient (r) analysis separately for 0-15 and 15-30 cm soil depths.

The significance of the correlation coefficients was interpreted at the appropriate probability levels.

Results and discussion

The correlation coefficients between different potassium fractions and physico-chemical properties of soil at 0-15 and 15-30 cm depths are presented in Tables 1 and 2, respectively. The results indicated that potassium fractions were differently associated with soil physical and chemical properties. Organic carbon and available N, P, K and S showed predominantly strong positive relationships with potassium fractions, whereas most physical properties and some chemical properties exhibited weak or non-significant associations.

1. Correlation of different k fractions with physical properties

1.1 Bulk density, particle density, porosity

Data presented in table 1 showed that the different potassium fractions, viz., water-soluble K, exchangeable K, non-exchangeable K, lattice K and total K, showed non-significant negative correlations with bulk density (-0.507, -0.482, -0.460, -0.565 and -0.557) and porosity (-0.063, 0.097, -0.119, -0.190 and -0.174,), whereas particle density showed significant negative correlations with water-soluble K (-0.580*), non-exchangeable K (-0.594*), lattice K (-0.755**) and total K (-0.734**), while the correlation with exchangeable K (-0.390) was non-significant at 0-15 cm depths respectively under long term fertilizer experiment in soybean safflower cropping sequence in vertisols. Data presented in table 2 showed that the different potassium fractions, viz., water-soluble K, exchangeable K, non-exchangeable K, lattice K and total K, showed non-significant negative correlations with bulk density (-0.378, -0.511, -0.429, -0.469 and -0.500) and porosity (-0.105, 0.001, -0.173, -0.210 and -0.095). Particle density showed significant negative correlations with non-exchangeable K (-0.603*), lattice K (-0.660*) and total K (-0.576*), whereas its correlations with water-soluble K (-0.504) and exchangeable K (-0.375) were non-significant at 15-30 cm depths respectively.

2. Correlation of different k fractions with chemical properties

2.1 Soil pH, soil EC, soil organic carbon

Data presented in table 1 showed that the different potassium fractions, viz., water-soluble K, exchangeable K, non-exchangeable K, lattice K and total K, showed negative correlations with soil pH (-0.418, -0.683*, -0.400, -0.364 and -0.385), positive correlations with EC (0.368, 0.122, 0.443, 0.525 and 0.510) and highly significant positive correlations with organic carbon (0.894**, 0.839**, 0.874**, 0.915** and 0.923**) at 0-15 cm depths respectively. It was observed from Table 2 that the different potassium fractions, viz., water-soluble K, exchangeable K, non-exchangeable K, lattice K and total K, showed negative correlations with soil pH (-0.328, -0.698*, -0.413, -0.336 and -0.346), positive correlations with EC (0.187, -0.089, 0.198, 0.240 and 0.148, respectively) and highly significant positive correlations with organic carbon (0.879**, 0.812**, 0.909**, 0.915** and 0.926**), at 15-30 cm depths respectively.

The strongest association was observed between organic carbon and total K. The positive relationship indicates that improvement in soil organic matter was associated with greater accumulation and retention of potassium in both active and reserve pools. Organic matter can support nutrient cycling and contribute to the retention of K in soil. Similar relationships have been reported by Pannu et al. (2002) [16], Arora et al. (2003) [17], Jatav et al. (2012) [18] and Irshad et al. (2020) [19].

2.2 Soil available nitrogen, phosphorus, potassium

Data presented in table 1 showed that the different potassium fractions, viz., water-soluble K, exchangeable K, non-exchangeable K, lattice K and total K, showed highly significant positive correlations with available N (0.924**, 0.823**, 0.934**, 0.931** and 0.945**),

available P (0.844**, 0.784**, 0.843**, 0.841** and 0.855**), available K (0.833**, 0.999**, 0.844**, 0.746** and 0.781**) and available S (0.883**, 0.849**, 0.899**, 0.884** and 0.901**) at 0-15 cm depths respectively. It was observed from Table 2 that the different potassium fractions, viz., water-soluble K , exchangeable K , non-exchangeable K , lattice K and total K , showed highly significant positive correlations with available N (0.920**, 0.797**, 0.958**, 0.914** and 0.903**), available P (0.807**, 0.801**, 0.834**, 0.802** and 0.835**), available K (0.769**, 0.999**, 0.811**, 0.718** and 0.751**) and available S (0.765**, 0.948**, 0.827**, 0.789** and 0.802**) at 15-30 cm depths respectively.

The positive association indicates that soils with better N availability also tended to maintain higher amounts of different K fractions. This may reflect the cumulative effect of balanced nutrient management on overall soil fertility rather than a direct effect of N on individual K pools. Similar positive associations have been reported by Athokpam *et al.* (2010) [20] and Dubey *et al.* (2015) [21]. The close positive association suggests that improvement in P availability occurred along with improvement in K status under long-term nutrient management.

This may reflect the beneficial effect of balanced fertilization on the overall nutrient-supplying capacity of the soil. Similar observations were reported by Majumdar *et al.* (2005) [22] and Dotaniya *et al.* (2023) [23].

Available potassium exhibited the strongest relationship with exchangeable K ($r = 0.999$) at both depths. Significant positive relationships were also observed between available K and water-soluble, non-exchangeable, lattice and total K . The very strong association with exchangeable K confirms the close relationship between the available and exchangeable pools. The positive relationships with the other K fractions further indicate the dynamic equilibrium existing among different forms of soil K , whereby reserve forms can contribute to replenishment of the available pool. Similar relationships were reported by Chaudhary *et al.* (1997) [24], Das *et al.* (2000) [25] and Lokya *et al.* (2018) [26].

The positive relationship suggests that higher S availability was associated with greater K status. This may be due to the common response of these nutrients to long-term balanced fertilizer and organic matter management.

Table 1. Relationship of different potassium fractions (0-15 cm) with physico-chemical properties of soil.

Soil properties	Water soluble K	Non-Exchangeable K	Exchangeable K	Lattice K	Total K
Particle density	-0.580*	-0.594*	-0.390 ^{NS}	-0.755**	-0.734**
Bulk density	-0.507 ^{NS}	-0.460 ^{NS}	-0.482 ^{NS}	-0.565 ^{NS}	-0.557 ^{NS}
Porosity	-0.063 ^{NS}	-0.119 ^{NS}	0.097 ^{NS}	-0.190 ^{NS}	-0.174 ^{NS}
pH	-0.418 ^{NS}	-0.400 ^{NS}	-0.683*	-0.364 ^{NS}	-0.385 ^{NS}
EC	0.368 ^{NS}	0.443 ^{NS}	0.122 ^{NS}	0.525 ^{NS}	0.510 ^{NS}
Organic carbon	0.894**	0.874**	0.839**	0.915**	0.923**
Available N	0.924**	0.934**	0.823**	0.931**	0.945**
Available P	0.844**	0.843**	0.784**	0.841**	0.855**
Available K	0.833**	0.844**	0.999**	0.746**	0.781**
Available S	0.883**	0.899**	0.849**	0.884**	0.901**

Table 2. Relationship of different potassium fractions (15-30 cm) with physico-chemical properties of soil.

Soil properties	Water soluble K	Non-Exchangeable K	Exchangeable K	Lattice K	Total K
Particle density	-0.504 ^{NS}	-0.603*	-0.375 ^{NS}	-0.660*	-0.576*
Bulk density	-0.378 ^{NS}	-0.429 ^{NS}	-0.511 ^{NS}	-0.469 ^{NS}	-0.500 ^{NS}
Porosity	-0.105 ^{NS}	-0.173 ^{NS}	0.001 ^{NS}	-0.210 ^{NS}	-0.095 ^{NS}
pH	-0.328 ^{NS}	-0.413 ^{NS}	-0.698*	-0.336 ^{NS}	-0.346 ^{NS}
EC	0.187 ^{NS}	0.198 ^{NS}	-0.089 ^{NS}	0.240 ^{NS}	0.148 ^{NS}
Organic carbon	0.879**	0.909**	0.812**	0.915**	0.926**
Available N	0.920**	0.958**	0.797**	0.914**	0.903**
Available P	0.807**	0.834**	0.801**	0.802**	0.835**
Available K	0.769**	0.811**	0.999**	0.718**	0.751**
Available S	0.765**	0.827**	0.948**	0.789**	0.802**

Conclusion

The study demonstrated that long-term nutrient management significantly influenced the distribution and interrelationship of different potassium fractions in Vertisol under the soybean-safflower cropping sequence. The correlation analysis revealed that organic carbon and available N , P , K and S were consistently and significantly positively associated with water-soluble, exchangeable, non-exchangeable, lattice and total K at both soil depths. Available K showed a particularly strong positive relationship with exchangeable K ($r = 0.999$), indicating the close association between the readily available and exchangeable K pools. In contrast, bulk density, porosity, EC and CaCO_3 generally showed non-significant relationships with K fractions. Particle

density exhibited significant negative relationships with selected K fractions, while soil pH was negatively associated with exchangeable K . Overall, the findings indicate that integrated application of mineral fertilizers with FYM, particularly 100% NPK + FYM @ 5 t ha⁻¹, favoured the maintenance of higher potassium status and was associated with improved soil fertility under long-term soybean-safflower cropping sequence.

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