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Tupaki Lokya
Department of Soil Science and Agriculture Chemistry, Dr. PDKV, Akola, Maharashtra, India

DV Mali
Department of Soil Science and Agriculture Chemistry, Dr. PDKV, Akola, Maharashtra, India

SD Jadhao
Department of Soil Science and Agriculture Chemistry, Dr. PDKV, Akola, Maharashtra, India

Corresponding Author:
Tupaki Lokya
Department of Soil Science and Agriculture Chemistry, Dr. PDKV, Akola, Maharashtra, India

Effect of potassium fertilization on different forms of potassium in vertisol under soybean

Tupaki Lokya, DV Mali and SD Jadhao

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Abstract
A field investigation was carried out during Kharif 2015–16 to study the influence of graded levels of potassium on different potassium fractions in soil under soybean cultivated on farmers' fields in Vertisols at Kanehri village, Tahsil Barshitakli, District Akola. The experiment consisted of four potassium treatments with six replications, where each farmer represented one replication, and was laid out in a Randomized Block Design. The treatments included 30:75:00 (T_1), 30:75:30 (T_2), 30:75:60 (T_3), and 30:75:90 kg NPK ha^{-1} (T_4). Results indicated that progressive application of potassium significantly enhanced all soil potassium fractions. The highest concentrations of water-soluble K (34 mg kg^{-1}), exchangeable K (152 mg kg^{-1}), non-exchangeable K (586 mg kg^{-1}), lattice K (10535 mg kg^{-1}), and total K (11305 mg kg^{-1}) were recorded with the application of 30:75:90 kg NPK ha^{-1}. Among the different fractions, lattice K dominated, followed by non-exchangeable K, exchangeable K, and water-soluble K. The proportional contribution of potassium fractions to total K followed the order: lattice K (93.29%) > non-exchangeable K (5.14%) > exchangeable K (1.32%) > water-soluble K (0.26%). Significant and positive correlations among different potassium fractions indicated a dynamic equilibrium in soil. The contribution of non-exchangeable potassium to total potassium uptake increased with decreasing potassium application rates, with the maximum contribution (22.39 kg ha^{-1} and 84.87%) observed under no potassium application. Potassium use efficiency was higher at lower potassium levels, recording a maximum value of 5.24% at 30 kg K_2O ha^{-1}.

Keywords: Vertisols, soybean, water-soluble potassium, exchangeable potassium, non-exchangeable potassium, lattice potassium

Introduction
Potassium is an essential macronutrient that exists in soils in several distinct forms differing in their availability to plants. These forms include soil solution potassium, exchangeable potassium, non-exchangeable potassium, and mineral or lattice potassium, which continuously interact to maintain equilibrium in the soil system (Martin and Sparks, 1985; Sparks and Huang, 1985) [8, 16]. Among these, potassium in the soil solution represents the immediate source for plant uptake, although its concentration is generally low and fluctuates widely due to plant absorption, leaching, and replenishment from other pools (Sparks, 1980) [14].
Exchangeable potassium is retained on negatively charged sites of clay minerals and organic matter and serves as an important readily available reservoir for crops. Uptake of potassium by plants temporarily disturbs the equilibrium between soil solution and exchangeable potassium, resulting in the release of exchangeable potassium into the soil solution. Vertisols and black cotton soils are known to possess relatively higher levels of exchangeable potassium compared to other soil types such as red, lateritic, and alluvial soils (Sekhon *et al.*, 1992) [13].
Non-exchangeable potassium is primarily held within the interlayer spaces of micaceous and vermiculitic clay minerals and is not directly available but can contribute to plant nutrition under conditions of potassium depletion in soil solution and exchangeable pools (Rich, 1972; Sparks, 2000) [12, 15]. Mineral or lattice potassium constitutes the major fraction of total soil potassium and becomes available only through long-term weathering processes.
Although several studies have documented the behavior of potassium fractions under different nutrient management practices (Gajbhiye, 1985; Srinivasa Rao *et al.*, 2002; Jadhao *et al.*, 2015) [2, 17, 4], information on potassium dynamics under graded potassium levels along with

recommended nitrogen and phosphorus doses in soybean cultivated on farmers' fields in Vertisols is limited. Therefore, the present study was undertaken to evaluate the influence of different potassium application rates on soil potassium fractions, their interrelationships, and potassium use efficiency under soybean cultivation.

Materials and Methods

A field experiment on soybean was conducted during the Kharif season of 2015–16 on farmers' fields located at Kanehri village, Tahsil Barshitakli, District Akola, Maharashtra. The soil of the experimental site was classified as Vertisol. The experiment comprised four potassium treatments with six replications, each farmer representing one replication, and was laid out in a Randomized Block Design. The treatments were:T_1 – 30:75:00 kg NPK ha^{-1}, T_2 – 30:75:30 kg NPK ha^{-1}, T_3 – 30:75:60 kg NPK ha^{-1},T_4 – 30:75:90 kg NPK ha^{-1}. Composite soil samples were collected after harvest using a soil auger, air-dried under shade, ground, and passed through a 2-mm sieve. The processed samples were stored in labeled cloth bags for laboratory analysis.

Water-soluble potassium was determined by extracting soil with distilled water (1:5 soil-water ratio) followed by estimation using a flame photometer (Pratt, 1965) [10]. Exchangeable potassium was extracted using neutral normal ammonium acetate and quantified by flame photometry (Knudsen *et al.*, 1982) [7]. Non-exchangeable potassium was estimated by boiling soil with 1 N nitric acid (1:10 ratio) and measuring potassium concentration in the extract (Wood and DeTurk, 1941) [9]. Total potassium was determined using hydrofluoric acid digestion (Jackson, 1967) [3]. Lattice potassium was calculated as the difference between total potassium and the sum of water-soluble, exchangeable, and non-exchangeable potassium fractions (Ranganathan and Satyanarayana, 1980) [11].

Results and Discussion

Water-Soluble Potassium

Water-soluble potassium content at harvest varied from 26 to 34 mg kg^{-1}. An increase in potassium fertilization resulted in a progressive rise in water-soluble K. The highest value (34 mg kg^{-1}) was recorded with the application of 30:75:90 kg NPK ha^{-1}, followed by 30:75:60 kg NPK ha^{-1} (30 mg kg^{-1}). The lowest concentration (26 mg kg^{-1}) was observed under the treatment receiving no potassium (30:75:00 kg NPK ha^{-1}). The increase in water-soluble K may be attributed to a higher concentration of potassium ions in the soil solution due to increased fertilizer application. The contribution of water-soluble K to total potassium ranged from 0.24 to 0.30%, indicating its relatively small share among the various potassium fractions. Comparable findings have been reported earlier, where increasing potassium levels enhanced different forms of soil potassium (Gajbhiye, 1985; Srinivas Rao *et al.*, 2002; Jadhao *et al.*, 2015) [2, 4].

Exchangeable Potassium

Exchangeable potassium content ranged between 139 and 152 mg kg^{-1} and followed a trend similar to that observed for water-soluble K. The highest exchangeable K content (152 mg kg^{-1}) was recorded with the application of 30:75:90 kg NPK ha^{-1}, followed by 30:75:60 kg NPK ha^{-1}. The minimum value (139 mg kg^{-1}) was associated with the treatment without potassium application (30:75:00 kg NPK ha^{-1}). The increase in exchangeable K with higher potassium levels may be due to the saturation of exchange sites by added potassium. The proportion of exchangeable K to total potassium varied from 1.29 to 1.35%, which was slightly higher than that of water-soluble K. Similar increases in exchangeable potassium with graded fertilizer application have been reported by Kadrekar (1976) [6], More and Gawali (1999) [9], Jawanjal (2002) [5], and Jadhao *et al.* (2015) [4].

Non-Exchangeable Potassium

Non-exchangeable potassium content ranged from 549 to 586 mg kg^{-1} and increased with higher potassium application rates. The maximum non-exchangeable K content (586 mg kg^{-1}) was observed with the application of 30:75:90 kg NPK ha^{-1}, followed by 30:75:60 kg NPK ha^{-1}, while the lowest value (549 mg kg^{-1}) was recorded under 30:75:00 kg NPK ha^{-1}. The substantial contribution of non-exchangeable K to the total potassium pool suggests partial fixation of added potassium within the interlayer spaces of clay minerals. This emphasizes the importance of organic amendments, which may aid in the gradual release of fixed potassium. The increase in non-exchangeable K under 30:75:90 kg NPK ha^{-1} was 6.5% higher than the treatment without potassium and 4.64% higher than 30:75:30 kg NPK ha^{-1}, indicating the beneficial effect of higher potassium levels on this pool. Similar trends have been reported by Bhalerao and Pharande (2003) [1], Talashikar *et al.* (2006) [18], and Jadhao *et al.* (2015) [4].

Lattice Potassium

Lattice potassium content at harvest ranged from 10,047 to 10,535 mg kg^{-1} and increased marginally with increasing potassium application. The highest lattice K content (10,535 mg kg^{-1}) was recorded with 30:75:90 kg NPK ha^{-1}, followed by 30:75:60 kg NPK ha^{-1} (10,351 mg kg^{-1}), whereas the lowest content (10,047 mg kg^{-1}) was associated with 30:75:00 kg NPK ha^{-1}. Lattice potassium constituted the major share of total potassium, contributing between 93.19 and 93.36%, indicating that mineral-bound potassium is the dominant form in Vertisols. These findings are in agreement with earlier reports (Bhalerao and Pharande, 2003; Talashikar *et al.*, 2006; Jadhao *et al.*, 2015) [1, 18, 4].

Total Potassium

Total potassium content varied from 10,762 to 11,305 mg kg^{-1} and showed a positive response to increasing potassium fertilization. The maximum total K content (11,305 mg kg^{-1}) was observed with the application of 30:75:90 kg NPK ha^{-1}, followed by 30:75:60 kg NPK ha^{-1}, while the minimum was recorded in the absence of potassium application. Similar responses of total potassium to fertilizer application have been reported earlier (Bhalerao and Pharande, 2003; Talashikar *et al.*, 2006; Jadhao *et al.*, 2015) [1, 18, 4]. The dominance of potassium fractions followed the order: lattice K > non-exchangeable K > exchangeable K > water-soluble K.

Relationship among Soil Potassium Fractions

All potassium fractions exhibited significant and positive correlations with one another, indicating a dynamic equilibrium among different potassium pools in the soil (Sparks and Huang, 1985) [16]. The strongest association was observed between lattice potassium and total potassium (r = 0.999**), followed by non-exchangeable potassium and total potassium (r = 0.964**), suggesting that these pools are closely related to the total potassium status of the soil.

Contribution of Non-Exchangeable Potassium to Total Potassium Uptake

The contribution of non-exchangeable potassium to total potassium uptake ranged from 2.60 to 22.39 kg ha⁻¹. The highest contribution was recorded under the treatment without potassium application (30:75:00 kg NPK ha⁻¹), followed by 30:75:30 kg NPK ha⁻¹, whereas the lowest contribution was observed with 30:75:90 kg NPK ha⁻¹. This indicates that the contribution of non-exchangeable potassium to crop uptake increased as the rate of potassium application decreased. The percentage contribution ranged from 9.87 to 84.87%, with the highest contribution occurring under low potassium levels, suggesting greater reliance on non-exchangeable potassium when external potassium supply is limited.

Potassium Use Efficiency

Potassium use efficiency varied from 3.36 to 5.24%. The highest use efficiency (5.24%) was recorded at the lowest potassium application rate (30 kg K_2O ha⁻¹), followed by 30:75:60 kg NPK ha⁻¹, whereas the lowest efficiency (3.36%) was observed with 30:75:90 kg NPK ha⁻¹. This trend indicates that potassium use efficiency decreases with increasing potassium application rates, as higher efficiency is generally achieved at lower fertilizer levels due to greater crop response per unit of applied nutrient.

Table 1: Effect of different levels of potassium on potassium fractions at harvest of soybean

Treatments	Potassium fractions (mg kg^{-1})				
	WS. K	Ex. K	Non-Ex. K	Lattice K	Total K
T_1 - 30:75:00 kg NPK ha^{-1}	26	139	549	10047	10762
T_2 - 30:75:30 kg NPK ha^{-1}	27	143	560	10195	10925
T_3 - 30:75:60 kg NPK ha^{-1}	30	146	572	10351	11098
T_4 - 30:75:90 kg NPK ha^{-1}	34	152	586	10535	11305
SE(m)±	0.43	4.03	1.76	29.68	27.96
CD at 5%	1.31	12.07	5.32	89.45	84.28

Table 2: Effect of different levels of potassium on contribution of different forms of K to total K

Treatments	Potassium fractions (mg kg^{-1})			
	WS. K	Ex. K	Non-Ex. K	Lattice K
T_1 - 30:75:00 kg NPK ha^{-1}	0.24	1.29	5.10	93.36
T_2 - 30:75:30 kg NPK ha^{-1}	0.25	1.31	5.13	93.31
T_3 - 30:75:60 kg NPK ha^{-1}	0.27	1.31	5.15	93.27
T_4 - 30:75:90 kg NPK ha^{-1}	0.30	1.35	5.18	93.19

Table 3: Relationship among soil K fractions

	WS-K	Ex.-K	Av.-K	NEK	LK	TK
WS-K	1.000					
Ex.-K	0.600**	1.000				
Av.-K	0.786**	0.964**	1.000			
NEK	0.630**	0.555**	0.640**	1.000		
LK	0.545**	0.514*	0.585**	0.866**	1.000	
TK	0.572**	0.546**	0.618**	0.964**	0.999**	1.000

* Significant at 5% level ** Significant at 1% level

Table 4: Contribution of non-exchangeable K to total K uptake

Treatments	Contribution of non-exchangeable K to total K uptake				
	Yield (q ha^{-1})		Contribution of non-exchangeable K to total K uptake (Kg/ha)	Per cent contribution (%)	KUE (%)
	Grain	straw			
T_1 - 30:75:00 kg NPK ha^{-1}	14.19	21.02	22.39	84.87	-
T_2 - 30:75:30 kg NPK ha^{-1}	15.76	25.06	11.53	29.29	5.24
T_3 - 30:75:60 kg NPK ha^{-1}	16.56	26.37	5.06	10.24	3.95
T_4 - 30:75:90 kg NPK ha^{-1}	17.21	27.04	2.60	9.87	3.36

Conclusion

The results of the present investigation indicate that the application of 30:75:90 kg N, P_2O_5 and K_2O ha⁻¹ significantly enhanced all soil potassium fractions compared to the other treatments. Among the different potassium pools, the order of dominance was lattice K (LK) > non-exchangeable K (NEK) > exchangeable K (Ex. K) > water-soluble K (WS K). A significant and positive interrelationship was observed among the various potassium fractions, suggesting a dynamic equilibrium between them. In contrast, higher potassium use efficiency and greater contribution of non-exchangeable potassium to total potassium uptake were recorded at lower levels of potassium application, indicating more efficient utilization of potassium under reduced fertilizer inputs.

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