

Forms, Adsorption and Fixation of K in Some Swell-Shrink Soils of Vidarbha

K.S. GAJBHIYE, S.T. GAIKAWAD, J.L. SEHGAL AND RATNA GUPTA

National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur 440 010

Abstract: Total K content in the soils ranged from 205 to 950 mg 100g⁻¹, of which water soluble, exchangeable, acid and fixed forms of K contributed 0.19, 3.01, 0.91 and 2.73 per cent respectively. The variation amongst the soils was attributed to geomorphic pattern, texture and clay content. The regression of solution K on the other forms of K could be expressed as : $K_{sol} = 0.014 + 0.100 K_{exch} - 0.059 K_{acid} - 0.027 K_{fix}$ ($R = 0.611$).

Of the added K to soil, 49 per cent became exchangeable, and 39 per cent fixed. Sixty six per cent of the fixed K (1 me 100g⁻¹) could be desorbed by 0.5 N HCl and be considered as moderately released K; the remaining 34 per cent was difficultly released K.

Swell-shrink soils in Vidarbha are being categorised for medium to high level of available K. Hence, barring a few affluent farmers, the practice of K fertilization to crops in the region is very limited. During recent decade, the cropping intensity has increased with cultivation of high yielding cultivars and N and P application. It is, therefore, pertinent to re-examine the soil and crop response to applied K. Hence, the studies on the distribution of various forms of K in soils and adsorption and fixation of applied K are imperative.

MATERIALS AND METHODS

Surface soil samples (0-20 cm) from 28 farm holdings comprising three soil orders (Entisol, Inceptisol and Vertisol) occurring in Sawangi watershed near Nagpur of

Vidarbha region were collected, processed, and extracted sequentially for different forms of K: water soluble, exchangeable (1N NH₄OAc), acid soluble (0.5N HCl) and fixed (boil, 1N HNO₃) by standard procedures (Jackson 1982 ; Hesse 1971). Total K (HF digestion) was extracted separately.

For adsorption and fixation studies, the soils were incubated for 30 days at room temperature maintaining the moisture at 33 kPa field capacity. In 500 ml polypropylene beaker 100 g soil (2 mm) was taken in duplicate. To one set, 1 mg K per g soil was added in the form of KCl. The other set was kept as control. The loss of moisture was corrected alternate day by adding distilled water on weight loss basis. After incubation period, the treated and untreated soil was extracted sequentially with water and 1N

NH₄OAc (pH 7.0).

Adsorbed and fixed K were computed as : the amount of K extracted with water was denoted as water soluble K (K_{sol}); the difference of K_{sol} between treated and untreated soil was referred to as unreacted K (K_{unr}).

$$K_{unr} = K_{sol} (\text{treated}) - K_{sol} (\text{untreated}) \text{ ---- (a)}$$

The value obtained after deducting unreacted K (K_{unr}) from added K (K_{add}), was considered as adsorbed K or reacted K (K_{adb})

$$K_{adb} = K_{add} - K_{unr} \text{ ----(b)}$$

Considering the pattern of available K, crop uptake and the yields, all adsorbed K (K_{adb}) may not necessarily justify to be called as fixed K (K_{fix}). The amount of K recovered with cationic exchange is well correlated with crop uptake and yields. In this context, a portion of the adsorbed K that was desorbed with cationic exchange reaction (1N NH₄OAc, pH 7.0) was referred to as exchangeable K (K_{exch}). As such it would not be accounted for fixed K (K_{fix}).

The value of increased exchangeable K was computed by difference between K_{exch} of treated and untreated soil.

$$\begin{aligned} \text{Increased } K_{exch} \\ = K_{exch} (\text{treated}) - K_{exch} (\text{Untreated}) \text{ ----(c)} \end{aligned}$$

The K left over in soil after deducting increased K_{exch} from K_{adb} was designated as nonexchangeable K or fixed K (K_{fix})

$$\begin{aligned} K_{fix} &= K_{adb} - \text{increased } K_{exch} \text{ -----(d)} \\ &= (b) - (c) \end{aligned}$$

$$K_{fix} \text{ capacity or } \% K_{fix} = \frac{K_{fix} \times 100}{K_{add}} \text{ ----(e)}$$

The fixed K was subsequently desorbed with 0.5 N HCl and 1N HNO₃ (boil) in sequence.

The soils are calcareous (5.0 to 17.8 % CaCO₃), slightly alkaline in reaction (pH 7.4 to 8.3) and normal in salts content (EC ds/m⁻¹ = <0.20). The available K status was 67 to 250 ppm.

RESULTS AND DISCUSSION

Forms of K : Total K content ranged from 205 to 950 with the average of 484 mg 100g⁻¹ soil; water soluble K from 0.3 to 2.0 with the average of 0.98 mg 100g⁻¹; exchangeable K from 4.3 to 28.0 with the average of 14.5 mg 100g⁻¹; acid soluble K from 0.8 to 8.0 with the average of 4.5 mg 100g⁻¹, and fixed K from 3.0 to 28.0 with the average of 13.2 mg 100g⁻¹ soil (Table 1). Though these soils belonged to the same agroclimatic region and developed from the same parent materials, yet they showed considerable variation in the status of different forms of K. The status of total K, fixed K, and exchangeable K, was observed to be higher in Vertisol followed by Inceptisol and Entisol.

Within the orders of Vertisol and Entisol, there was one series each and therefore the variation as stated for order level remained the same. In case of Inceptisol there were

TABLE 1. Forms of K (mg 100⁻¹ soil) in swell-shrink soils of Sawangi watershed

Forms of K	Sawangi-1 Lithic Ustorthent	Sawangi-2 Lithic Ustochrept	Sawangi-3 Lithic Ustochrept	Sawangi-4 Typic Ustochrept	Sawangi-5 Udic Ustochrept	Sawangi-6 Typic Chromustert	Over all
Watersoluble							
Range	0.3-0.7	0.4-0.8	0.4-1.0	0.4-1.4	0.8-2.0	0.8-1.8	0.3-2.0
Average	0.5(0.18)*	0.5(0.18)	0.8(0.17)	0.9(0.14)	1.8(0.34)	1.2(0.17)	0.98(0.19)
Exchangeable (1N NH₄OAc)							
Range	4.3-8.2	5.0-9.8	7.0-20.8	8.0-20.2	10.0-27.0	12.0-28.0	4.3-28.0
Average	7.7(2.85)	6.2(2.26)	13.5(2.85)	12.8(2.00)	23.0(4.34)	24.0(3.38)	14.5(3.01)
Acid soluble (0.5N HCl) moderately release							
Range	0.8-2.0	1.5-4.0	2.0-8.0	2.5-4.5	3.0-8.0	4.0-8.0	0.8-8.0
Average	1.6(0.56)	3.0(1.09)	4.3(0.91)	3.8(0.59)	6.5(1.23)	7.5(1.06)	4.5(0.91)
Fixed (1N HNO₃ - boiling) difficultly release							
Range	3.0-6.0	5.0-10.0	5.0-26.3	6.3-12.5	15.0-28.0	14.0-27.5	3.0-28.0
Average	5.0(1.85)	7.1(2.58)	11.5(2.43)	8.7(1.36)	22.5(4.24)	24.0(3.38)	13.2(2.73)
Total (HF digestion)							
Range	240-290	205-365	322-670	490-770	480-830	450-950	205-950
Average	270(100)	275(100)	474(100)	641(100)	530(100)	710(100)	484(100)

* Figure in parentheses indicates % of total K; ** Series name abbreviated as Swg in the text

TABLE 2. Coefficient of correlation(r) among different forms of K and with soil separates

	Water soluble K	Exch. K	Acid K	Fixed K	Total K
Water soluble K	—	0.774*	0.545*	0.449*	0.276
Exch.K	—	—	0.796*	0.732*	—
Acid K	—	—	—	0.886*	0.595*
Fixed K	—	—	—	—	—
Silt	-0.500	-0.745	-0.847*	-0.731*	-0.912*
Clay	0.849	0.801	0.791*	0.809*	0.508

* Significant at 5% level

four series (Swg-2, Swg-3, Swg-4 and Swg-5) differing quite considerably, Swg-2 and Swg-3, belong to the same great group of Lithic Ustochrept, Swg-3 had higher amount of all the forms of K (with exception of solution K) than Swg-2. The Swg-4 series belonging to great group of Typic Ustochrept had higher content of total K and lower content of fixed, acid and exchangeable K than the Swg-5 series of Udic Ustochrept. The variation in different forms of K at soil family level could not be visualised as all these series belong to the family of mineralogy (Montmorillonitic) and the temperature (hyperthermic). This indicates that the soil forming factors and processes giving rise to the development of particular diagnostic characteristics to the soil series were responsible to cause the variation in distribution of different forms of K. Gajbhiye et al. (1990) discussed the variation in available K status due to texture, slope and soil depth. The distribution of K in these soils followed a definite geomorphic pattern and was related more to the condition of weathering. The existence of significant positive correlation of clay and that of a negative of silt with water soluble, exchangeable and nonexchangeable K (Table 2) also indicates the dominance of clay content in controlling such variation. Brar and Sekhon (1987) also reported that the variation in different forms of K in Benchmark soils of northern India, was caused due to variation in texture, intensity of surface weathering, organic carbon content, upward movement of soluble K with capillary rise and the leaching.

It could further be seen that bulk of the total K constituting about 93 per cent remained as inert or in nonextractable or lattice form. The remaining 7 per cent was contributed by water soluble, exchangeable, acid soluble and fixed forms of K by 0.19, 3.01, 0.91 and 2.73 per cent, respectively.

The readily available form of K constituting water soluble and exchangeable, and moderately available K (acid form) together formed only 4 per cent of the total K (Fig. 1).

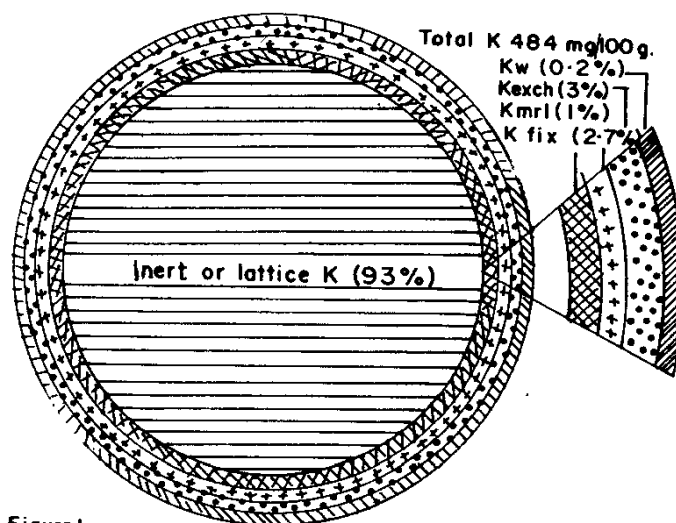


Figure 1. Distribution of total K (%) into different forms.

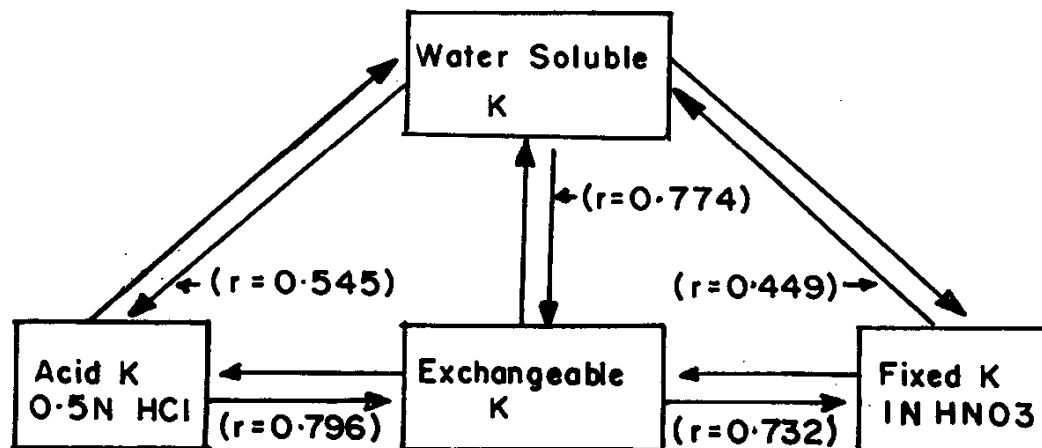
The coefficient of correlation in between various forms of K indicated that barring total K, the other forms significantly correlated with each other (Table 2). Water soluble K showed strongest degree of significant correlation with exchangeable K ($r = 0.774$) and weakest with fixed K ($r = 0.449$). Obviously exchangeable form of K

appeared a major reservoir replenishing solution K — the most immediate source of K to growing plant. Similarly exchangeable K had stronger co-efficient of correlation with acid form of K ($r = 0.796$) than fixed form of K ($r = 0.732$) indicating its recuperation in that order on depletion due to crop removal or any other cause. Acid soluble and fixed form of K together were referred to as nonexchangeable forms. Comparing the degree of coefficient of correlation (r values) between water soluble and exchangeable K, and that of exchangeable and nonexchangeable forms of K, there was much similarity in the degree of the values, showing the existence of some sort of equilibrium between them.

The occurrence of such equilibrium signifies the K supplying power of soil and K nutrition of plant. The removal of a portion of solution - K by plant uptake and/or by leaching causes some exchangeable K to move to solution - K and nonexchangeable forms of K to exchangeable K with the rate

being controlled by mass action. (Ramamoorthy & Velayutham 1978). The exchangeable K maintains equilibrium with K in solution, and together the exchangeable and solution K make up the available K. The setting up of equilibrium in between exchangeable and solution -K is thought to be a quicker process. The solution -K was found to be almost 10 per cent of exchangeable K.

The conversion of nonexchangeable K to solution - K can not be ruled out as there existed the significant correlation between solution K and nonexchangeable forms of K, though relatively weak, as compared to exchangeable K. This suggested that non-exchangeable forms of K also tend to maintain the level of solution - K to some extent. Obviously exchangeable K being highly correlated with solution K ($r = 0.774$), plays the most dominant role followed by nonexchangeable forms of K- the acid ($r = 0.545$) and fixed K ($r = 0.449$) to rejuvenate the level of solution K in soil. Thus, the K con-



centration in soil solution is not a straight forward function of exchangeable K but is also related to acid soluble (0.5 *N* HCl) and fixed forms of K (1*N* HNO₃ boiling) as well. This relationship can be expressed with the help of partial regression co-efficient model as : $K_{sol} = 0.014 + 0.100 K_{exch} - 0.059 K_{acid} - 0.027 K_{fix}$ (R = 0.611).

Absence of relationship between total K and other K forms was perhaps indicative of

extremely slow release of K from the minerals (Goswami & Bandyopadhyay 1978).

Adsorption and fixation of added K :

The magnitude of adsorption of applied K appeared to be almost similar in all these soils. After 30 days of K application, the unreacted K (K_{unr}) was recovered to the extent of 10 to 15 per cent leaving 85 to 90 per cent in soil (Table 3). It was assumed

TABLE 3. Transformation of added K (mg 100g⁻¹ soil) in soils of Sawangi watershed

Soils	Unreacted	Reacted Exch. K	K (K_{adb}) Nonexch/ fixed K	Desorption of fixed K	
				0.5 <i>N</i> HCl K	1 <i>N</i> HNO ₃ K
	(A)	(B)	(C + D)	(C)	(D)
Sawangi-1	11.8-17.2 (14.5)	48.0-54.0 (15.1)	34.4	13.0-21.0 (17.0)	9.0-18.7 (17.4)
Sawangi-2	8.1-14.0 (10.0)	43.0-57.0 (49.4)	40.6	17.5-30.0 (26.8)	10.0-18.6 (13.8)
Sawangi-3	8.7-13.6 (10.5)	32.5-60.0 (49.1)	40.4	16.6-40.0 (27.1)	8.5-26.5 (13.3)
Sawangi-4	9.5-16.1 (12.0)	42.0-54.0 (46.3)	41.7	22.5-35.0 (30.0)	7.3-18.9 (11.7)
Sawangi-5	10.1-16.8 (13.0)	39.0-51.0 (48.0)	39.0	23.5-31.0 (29.5)	6.5-14.0 (9.5)
Sawangi-6	10.1-17.2 (12.0)	38.5-57.0 (49.0)	39.0	21.5-30.0 (28.8)	7.0-15.0 (10.2)
Over all the soils	8.0-17.2 (12.0)	35.2-60.0 (48.8)	39.2	13.0-40.0 (26.5)	9.0-18.9 (12.7)

Figures in parenthesis indicate average values

that this portion of added K (88%) had undergone some sort of chemical reaction with soil matrix and was referred to as reacted or adsorbed K (K_{adb}).

As could be seen from subsequent desorption of adsorbed K in sequential manner, the cationic exchange reaction was the major one by which adsorbed K was recovered to the extent of 53 to 57 per cent, and was accounted to about 46 to 51 per cent of added K. It was postulated that K adsorbed on exchange complex could only come out with exchange reaction (1N NH_4OAc) and thus it was referred to as exchange form of K that was converted from added soluble K.

Thus, of the added K, on an average 12 per cent remained unreacted and 49 per cent could be recovered with exchange reaction, totalling to about 61 per cent. The remaining 39 per cent was assumed to have entered into some sort of reaction by which it was held in soil in nonexchangeable forms so firmly that it could not be recovered with relative ease with extractions (water and neutral normal NH_4OAc). just mentioned above. The apparent increase in nonexchangeable K due to addition of potassium, a process presumably known as potassium fixation, was about 39 per cent.

The magnitude of K fixation was in the range of 34 to 42 mg $100g^{-1}$ soil (0.87 to 1.08 me K) and was found to be correlated negatively with silt ($r = -0.546$) and positively with clay ($r = 0.603$), indicating the

dominance of clay fraction in this respect. Pal and Durge (1987) also reported that 60 per cent of added K was fixed by fine clay fraction of *swell-shrink* soils. According to them, the clay fraction is composed of more than 50 per cent of fine clay which is constituted by 70 to 80 per cent of smectite and 5 to 10 per cent of vermiculite minerals. The fixation of added K in present case might partly be due to vermiculite as it is known for K fixing mineral and partly due to smectite as reported by Pal and Durge (1987).

Desorption of fixed K : Entrapment of added or solution K in the lattice voids of clay structure, leads to unfavourable situation which renders K to become unavailable/or more difficultly available to plant. To assess the gravity of such situation, a sequential desorption of fixed K as reported in preceding section, was carried out in continuation of the experiment. It was observed (Table 3) that of the fixed K, about 70 per cent (17 to 30 mg $100 g^{-1}$ soil) could be desorbed with dilute acid extractant (0.5N HCl). This value was equal to 27 per cent of added K and was referred to as acid soluble K, and can be considered as moderately released K because of relative ease of extraction and of several evidences that this part of K also tends to meet the K requirement of growing plant.

The remaining 30 per cent of fixed K (10 to 17 mg $100 g^{-1}$ soil) which was equal to about 13 per cent of added K would be denoted as difficultly released K, as it was in close agreement (± 3) with those obtained in sequential extraction using 1N

HNO₃ (boiling) - a relatively violent reaction. This part of difficultly released K transformed from added K appeared to be related inversely to the original soil level of moderately released HCl-K ($r = -0.906$) and difficultly released HNO₃-K ($r = -0.842$). This indicates that soil possesses certain reserve value of K, and on stress this reserve K slowly transforms to readily available K depending upon the degree of fulfillment of K reserve capacity of soil. If the K reserve capacity of soil remains unsatisfied, the applied K gets converted into reserve K based on its unsatisfied state. In the present case, the soils appeared unsatisfied in K reserve status which might lead to fix the added K as mentioned above. Such soils begin to respond to K application only when enough K is added to saturate their fixation capacity (Sekhon & Velayutham 1978). It is, therefore, pertinent that the K fertilization to these soils may be taken into account, not only the plant K requirement but also the K-fixing capacity and in turn K reserve state of soil.

It is thus apparent that about 83 to 87 per cent of applied K could become available to growing plants under normal stress of K supplying power of soil. Only 13 to 17 per cent of applied K transformed to difficultly released state.

REFERENCES

- Brar, M.S. & Sekhon, G.S. (1987) Vertical distribution of potassium in five benchmark soil series in northern India. *J. Indian Soil Sci.* **35** = :732-735.
- Gajbhiye, K.S., Gaikwad, S.T., Sehgal, J.L., Bhaskar, K.S. & Ratna Gupta (1990) Status of available K and crop response in soils of Sawangi watershed in Vertisol region of Vidarbha. *Annual Report, NBSS&LUP, Nagpur.*
- Goswami, N.N. & Bandyopadhyay, B.K. (1978) Potassium dynamics in Alluvial soils, *In Potassium in Soil and Crops*. p 35- 48, (Pb). *Potash Research Instt. India, New Delhi.*
- Hesse, P.R. (1971) *Soil Chemical Analysis* John Murray Ltd. London.
- Jackson, M.L. (1982) *Soil Chemical Analysis*, Prentice Hall of India New Delhi.
- Pal, D.K. & Durge, S.L. (1987) Potassium release and fixation relations in some benchmark Vertisols of India in relation to their mineralogy. *Pedologie*, **xxxvii**-2, 103-116
- Ramamoorthy, B. & Velayutham, M. (1978) (*In*) *Soil Fertility Theory and Practice*, ICAR, New Delhi, p 156.
- Sekhon, G.S. & Velayutham, M. (1978) Limitation of present soil test interpretations for potassium and suggestion for modification; Indian experience. (*In*) *Potassium in Soil and Crops*. p.114-124. *Potash Research Instt. India, New Delhi.*