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Forms and Distribution of Potassium in Some Selected Soils of Sahibganj District, Jharkhand, Developed from Rajmahal Trap

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Distribution of different forms of potassium (K) was investigated in four representative pedons *viz.* P1: Lilatanr series (Lithic Ustorthents), P2: Rangamatiya series (Typic Haplustepts), P3: Jetkumarjari series (Vertic Endoaquepts) and P4: Dakshin Balua series (Typic Ustifluvents) developed from Rajmahal trap occurring on various landforms in Borio block of Sahibganj district, Jharkhand. The soils were moderately acidic to moderately alkaline in the surface (pH: 6.0 to 7.9), fine in texture (clay: 25.1 to 53.5%), low in soluble salt content (EC: 0.05 to 0.50 dS m^{-1}), medium to high in organic carbon (OC) (7.3-8.6 g kg^{-1}), and adequate in available K (surface mean 568 kg ha^{-1}). Water soluble K, exchangeable K, non-exchangeable K, lattice K and total K in the soils varied from 0.021 to 0.130, 0.2 to 1.011, 0.10 to 0.839, 36.35 to 86.43 and 38.46 to 88.21 cmol(p$^+$)kg^{-1}, respectively. The profile weighted mean (PWM) of different forms of K revealed the sequence: total K [56.87 cmol(p$^+$)kg^{-1}] > lattice K [55.95 cmol(p$^+$)kg^{-1}] > non-exchangeable K [0.469 cmol(p$^+$)kg^{-1}] > exchangeable K [0.410 cmol(p$^+$)kg^{-1}] > water soluble K [0.046 cmol(p$^+$)kg^{-1}]. The overall contribution of water soluble K, exchangeable K, non-exchangeable K and lattice K to total K were 0.081, 0.721, 0.825 and 98.38%, respectively. Based upon PWM-K, the water soluble K and exchangeable K in the pedons followed the sequence: P4 > P3 > P2 > P1 and P4 > P3 > P1 > P2, whereas non-exchangeable K, lattice K and total K followed the sequence: P4 > P2 > P3 > P1, suggesting maximum quantity of the forms of K in soils of flood plain and minimum in those of foot hills. Vertical distribution of different forms of K revealed no definite trend except water soluble K which showed somewhat gradual decrease down the depth of the pedons. Highly significant positive correlation existed between exchangeable K and available K (r = 0.993**), non-exchangeable K and lattice K (r = 0.864**) and lattice K and total K and (r = 0.999**). A regression equation *viz.* total K = 32.47 non-exchangeable K = 42.88 (R^2 = 0.752) is also proposed.

Key words: Forms of potassium, landforms, Rajmahal trap, profile weighted mean

Potassium (K) is one of the key nutrient elements required for crop growth and the dynamic equilibrium between different forms of K determine the K status of the soil and the potential of K supply to plants (Srinivasarao *et al.* 2002). The equilibrium is markedly affected when applied soluble K is either taken up by plants or leached down into lower soil horizons or converted to unavailable form. Major portion of soil K exists as part of mineral structure and in fixed or non-exchangeable form, with a small fraction as water soluble and exchangeable K in soil. The water soluble and exchangeable forms contribute to the pool of readily available K that is adsorbed on soil colloidal surface. The non-exchangeable K held between the adjacent tetrahedral layers of di- and tri-octahedral micas, vermiculites and intergrade clay minerals which serve as a reserve source of soil K, is released to the exchangeable pool when the latter is depleted by crop removal and/or leaching. Unavailable or lattice K occurring in the primary minerals such as feldspars and micas is insignificant as a source of immediate K supply to plants (Mortland 1961).

A thorough investigation regarding distribution of different forms of soil K with routine estimation of

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available K is essential for getting a clear picture of its availability to crop plants, since soil K is considered as an elusive element in the context of plant availability, most of its elusiveness being governed by the amount and type of clay present in the soil and the low hydration energy of K^+ which favours its entrapment in the interlayer space of micaceous minerals (McLean 1978). Furthermore, information on vertical distribution of K in soils is also very important since it indicates the depletion as well as accumulation pattern of K with respect to depth of soils (Saini and Grewal 2014).

Rajmahal trap is one of the oldest geomorphic units of eastern India, covering an area of 10360 km^2. Its formation is critically important in terms of stratigraphy, petrography and topographic configurations (Mandal 2018). Geologically, the area comprises of basaltic parent rock of Lower Jurassic Age (Mandal 2018) and hence soils in the region are expected to comprise considerable amount of hydroxyl interlayred smectite (HIS) in minerals in fine clay fractions (less than 0.2 μm) (Nayak *et al.* 2017). However, there is paucity of systematic information of soils of Rajmahal trap as well as their K dynamics. Therefore, the present investigation was undertaken to study the distribution of different forms of K with a view to generate a databank for the same in some selected soils of Borio block, Sahibganj district, Jharkhand developed from Rajmahal trap occurring on various landforms.

Materials and Methods

Site description

Borio block of Sahibganj district, Jharkhand lies between 24°57′36″ and 25°16′48″ N latitude and 87°25′00″ and 87°35′45″ E longitude covering an area of 38590 ha (24.13% of total geographical area of the district). The area falls under AESR 12.3 agro-ecological sub-region (Chhotanagpur Plateau, hot dry sub-humid with length of growing period 150 to 180 days) (Velayutham *et al.* 1999).

Collection and analysis of soils

Four pedons representing different landforms *viz.* foothills (P1: Lilatanr series - clayey skeletal, mixed, hyperthermic Lithic Ustorthents); undulating upland (P2: Rangamatiya series - fine, mixed, hyperthermic Typic Haplustepts); old alluvial plain (P3: Jetkumarjari series – fine, mixed, hyperthermic Vertic Endoaquepts); and young flood plain (P4: Dakshin Balua series – fine silty, mixed, hyperthermic Typic Ustifluvents) were selected for the present study. Horizon-wise soil profile samples of the respective pedons collected during field survey were used for soil analysis.

The air-dried soil samples (<2 mm) were analyzed for selected physicochemical properties *viz.* pH, electrical conductivity (EC), organic carbon (OC), cation exchange capacity (CEC), particle size distribution following standard procedures (Piper 1966; Jackson 1973). Different forms of K *viz.* water soluble K (by shaking 1:5, soil: water) (Grewal and Kanwar 1966), exchangeable K (by extracting with neutral 1 *N* ammonium acetate), 1*N* HNO_3 extractable K, total K (by HF-$HClO_4$ digestion) (Sparks 1996) were measured by flame photometer. The non-exchangeable K was computed by subtracting exchangeable K plus water soluble K from 1*N* HNO_3 extractable K. Lattice K was obtained by difference between total K and sum of water soluble, exchangeable and non-exchangeable K (Wiklander 1954). Interrelationship between the forms of K was explained by Pearson's correlation coefficient at 5 and 1% level of significance, using SPSS software ver. 22.

Results and Discussion

Physicochemical properties of soils

The surface soil pH varied from 6.0 (moderately acidic) to 7.9 (moderately alkaline) except that of pedon 4 which generally increased down the depth of the pedons with minor variation in the intermediate layers. The high pH (8.1 to 8.6) as observed in pedon 4 may be due to lower physiographic position nearer to the river where the accumulation of bases might have occurred to a considerable extent. The EC of the soils ranged from 0.05 to 0.50 dS m^{-1} indicating no constraint for growing crops due to low content of soluble salts. In general, most of the soils were fine in texture (silty clay to silty clay loam/silt loam) with clay content varying from 25.1 to 53.5%. The OC varied from 7.3 (medium) to 8.6 g kg^{-1} (high) in the surface and decreased down the depth of the pedons. The CEC of the soils ranged from 2.7 to 31.8 $cmol(p^+)kg^{-1}$ whereas, base saturation varied from 74 to 93% (Table 1). The available K in the soils ranged from 0.25 to 1.12 $cmol(p^+)kg^{-1}$ (Table 2) with profile weighted mean of 0.46 $cmol(p^+)kg^{-1}$ (Table 3), whereas in the surface it varied from 0.38 to 1.12 $cmol(p^+)kg^{-1}$ (Table 2) with a mean of 0.65 $cmol(p^+)kg^{-1}$ (568.7 kg ha^{-1}) (Table 3), and is therefore rich in available K content.

Table 1. Some physicochemical properties of the selected soils

Pedon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH (1:2.5 water)	EC (dS m^{-1})	OC (%)	CEC [cmol(p^+) kg^{-1})]	BS (%)
Soils of foothills: Lilatanr series - Clayey skeletal, mixed, hyperthermic Lithic Ustorthents										
P1	0-15	8.5	52	39.5	sicl	6.5	0.14	8.6	28.8	76
	15-36	12.8	42.4	44.8	sic	7.2	0.1	7.7	25.9	81
	36-65	14.6	31.5	53.9	c	6.9	0.14	5.2	27.1	80
Soils of undulating upland: Rangamatiya series - Fine, mixed, hyperthermic Typic Haplustepts										
P2	0-17	3.4	55.8	40.8	sic	7.2	0.15	7.3	22.7	85
	17-64	2.1	53.3	44.6	sic	7.3	0.1	1.9	27.7	86
	64-95	2	51.5	46.5	sic	7.5	0.12	1.6	27.5	88
	95-130	16.9	47.6	35.5	sicl	7.8	0.16	0.9	29.6	90
Soils of old alluvial plain: Jetkumarjari series – Fine, mixed, hyperthermic Vertic Endoaquepts										
P3	0-20	2.6	43.9	53.5	sic	6	0.09	8.8	25.8	74
	20-53	5.2	44.9	49.9	sic	7.6	0.1	6	27.9	86
	53-82	5.6	44.2	50.2	sic	7.5	0.07	5.8	28.7	86
	82-108	5.7	40.8	53.5	sic	7	0.18	4.5	30.8	82
	108-150	5.1	47.6	47.3	sic	7	0.3	4.3	31.8	82
Soils of young flood plain: Dakshin Balua series – Fine silty, mixed, hyperthermic Typic Ustifluvents										
P4	0-17	12.8	62.1	25.1	sil	7.9	0.5	7.7	13.3	90
	17-46	3.7	71	25.3	sil	8.1	0.35	4.9	10.1	92
	46-69	21.9	70	8.1	sil	8.6	0.25	3.1	2.8	93
	69-86	0.9	82.4	16.7	sil	8.4	0.27	1.1	7.7	92
	86-120	5.5	82	12.5	sil	8.4	0.23	1.3	5.1	92
	120-150	21.2	68	10.8	sil	8.6	0.26	1	2.7	93

Abbreviations: c-clay; sil-silt loam; sicl-silty clay loam; sic-silty clay

Distribution of different forms of potassium in soils

The distribution of forms of K and total K in different landforms are presented in table 2. The profile weighted mean (PWM) of the forms of K is furnished in table 3.

Water soluble K

The water soluble K in the soils ranged from 0.021 to 0.130 cmol(p^+)kg^{-1} with profile weighted mean of 0.046 cmol(p^+)kg^{-1} contributing 0.08% to total K. At surface, it varied from 0.054 to 0.130 cmol(p^+)kg^{-1} with a mean of 0.089 cmol(p^+)kg^{-1}. Water soluble K constituted 6.5 to 19.9% of available K. Similar findings were reported by Das *et al*. (2000) and Tarafdar and Mukhopadhyay (1986). In all the pedons, the surface horizon contained more water soluble K than the sub-surface. This may be due to application of K fertilizers or presence of higher organic matter content in the surface soil. In general, the vertical distribution pattern showed somewhat gradual decrease down the depth of the pedons. Based upon PWM-K, the water soluble K in the pedons followed the sequence P4 > P3 > P2 > P1 (Table 3), suggesting maximum water soluble K in soils of young flood plain and minimum in soils of foot hill landform.

Exchangeable K

The exchangeable K in the soils ranged from 0.20 to 1.011 cmol(p^+)kg^{-1} with profile weighted mean of 0.410 cmol(p^+)kg^{-1} contributing 0. 72% to total K. In the surface it varied from 0.322 to 1.011 cmol (p^+)kg^{-1} with a mean of 0.562 cmol(p^+)kg^{-1}. Similar finding was reported by Tarafdar and Mukhopadhyay (1986) in soils of Medinipur, Puruliya and Bankura districts of West Bengal. In all the pedons (except P2), the surface horizon contained more exchangeable K than the subsurface as was also reported by Das *et al.* (2000). Furthermore, the vertical distribution of exchangeable K down the depth of the pedons revealed regular oscillation, with maximum value in the surface followed by decrement in the sub-surface with repeating sequence thereafter. However, in case of P2, a gradual increase in exchangeable K is noted up to the third horizon, followed by decrease of the same. Such variation of exchangeable K might be due to the change in clay content following almost similar trend in the soil horizons down the depth of the pedon (Table 1). Based upon PWM-K, the exchangeable K in the pedons followed the sequence P4 > P3 > P1 > P2 (Table 3) suggesting maximum exchangeable K in soils of young flood plain and minimum in soils of undulating upland.

Table 2. Forms of potassium in the different pedons

Pedon	Depth (cm)	Different forms of potassium						
		Water soluble K	Exchangeable K	Available K	1 *N* HNO_3 extractable K	Non-exchangeable K	Lattice K	Total K
		[cmol(p^+)kg^{-1}]						
Soils of foothills: Lilatanr series - Clayey skeletal, mixed, hyperthermic Lithic Ustorthents								
P1	0-15	0.060	0.391	0.451	0.551	0.100	50.7	51.3
		(0.110)*	(0.762)	(0.879)	(1.074)	(0.195)	(98.9)	
	15-36	0.031	0.241	0.272	0.382	0.110	38.1	38.5
		(0.080)	(0.626)	(0.707)	(0.993)	(0.286)	(99.0)	
	36-65	0.031	0.492	0.523	0.572	0.049	36.3	36.9
		(0.084)	(1.332)	(1.416)	(1.549)	(0.133)	(98.5)	
Soils of undulating upland : Rangamatiya series - Fine, mixed, hyperthermic Typic Haplustepts								
P2	0-17	0.054	0.322	0.376	0.841	0.465	55.7	56.5
		(0.095)	(0.570)	(0.665)	(1.488)	(0.823)	(98.5)	
	17-64	0.042	0.340	0.382	0.983	0.601	58.9	59.8
		(0.070)	(0.568)	(0.638)	(1.643)	(1.004)	(98.4)	
	64-95	0.033	0.415	0.448	0.984	0.536	55.8	56.8
		(0.058)	(0.730)	(0.789)	(1.733)	(0.944)	(98.3)	
	95-130	0.035	0.401	0.436	0.622	0.186	45.7	46.3
		(0.075)	(0.865)	(0.940)	(1.342)	(0.401)	(98.7)	
Soils of old alluvial plain : Jetkumarjari series – Fine, mixed, hyperthermic Vertic Endoaquepts								
P3	0-20	0.130	0.522	0.652	1.182	0.530	80.3	81.5
		(0.159)	(0.641)	(0.800)	(1.450)	(0.650)	(98.6)	
	20-53	0.021	0.300	0.321	0.475	0.154	51.7	52.2
		(0.040)	(0.575)	(0.615)	(0.910)	(0.295)	(99.1)	
	53-82	0.023	0.423	0.446	0.600	0.154	40.4	41.0
		(0.056)	(1.031)	(1.088)	(1.463)	(0.375)	(98.5)	
	82-108	0.031	0.391	0.422	0.731	0.309	53.5	54.3
		(0.057)	(0.720)	(0.777)	(1.347)	(0.569)	(98.7)	
	108-150	0.035	0.400	0.435	0.500	0.065	44.1	44.6
		(0.078)	(0.898)	(0.976)	(1.122)	(0.146)	(98.9)	
Soils of young flood plain : Dakshin Balua series – Fine silty, mixed, hyperthermic Typic Ustifluvents								
P4	0-17	0.113	1.011	1.124	1.963	0.839	83.7	85.6
		(0.132)	(1.180)	(1.312)	(2.292)	(0.979)	(97.7)	
	17-46	0.093	0.622	0.715	1.781	1.066	86.4	88.2
		(0.105)	(0.705)	(0.810)	(2.018)	(1.208)	(98.0)	
	46-69	0.053	0.200	0.253	1.435	1.182	72.5	73.9
		(0.071)	(0.270)	(0.342)	(1.940)	(1.598)	(98.1)	
	69-86	0.044	0.513	0.557	1.612	1.055	69.4	71.0
		(0.061)	(0.722)	(0.784)	(2.269)	(1.485)	(97.7)	
	86-120	0.055	0.423	0.478	1.494	1.016	68.8	70.3
		(0.078)	(0.602)	(0.693)	(2.126)	(1.446)	(97.9)	
	120-150	0.062	0.321	0.383	1.883	1.500	83.3	85.1
		(0.072)	(0.377)	(0.449)	(2.211)	(1.761)	(97.8)	

*Figures within parentheses indicate per cent of total K

Non-exchangeable K

Non-exchangeable K is considered to be slowly available to plants over a longer period of time under K-stress when the solution and exchangeable K in soil reach the threshold level upon depletion of K by crop removal and leaching. The non-exchangeable K in the soils ranged from 0.049 to 0.839 cmol(p^+)kg^{-1} with profile weighted mean of 0.469 cmol(p^+)kg^{-1}, contributing 0.83% to total K. In the surface it varied from 0.10 to 0.839 cmol(p^+)kg^{-1} with a mean of 0.484 cmol(p^+)kg^{-1}. The vertical distribution of non-exchangeable K down the depth of the pedons showed no definite trend. However, lower amount of non-exchangeable K in the surface soil as compared to the subsoil as evident in pedon P2 and P4 might be ascribed to the release of non-exchangeable K to compensate the removal of water soluble K and exchangeable K by crop plants and leaching loss

Table 3. Profile weighted mean (PWM) of forms of potassium in different pedons

Pedon	Water soluble K	Exchangeable K	Non-exchangeable K	Lattice K	Total K
	[cmol (p^+) kg^{-1}]				
	Soils of foothills: Lilatanr series - Clayey skeletal, mixed, hyperthermic Lithic Ustorthents				
P1	0.034	0.388	0.080	40.23	40.73
	(0.083)*	(0.953)	(0.196)	(98.77)	
	Soils of undulating upland: Rangamatiya series - Fine, mixed, hyperthermic Typic Haplustepts				
P2	0.039	0.372	0.456	54.17	55.04
	(0.071)	(0.676)	(0.828)	(98.42)	
	Soils of old alluvial plain: Jetkumarjari series – Fine, mixed, hyperthermic Vertic Endoaquepts				
P3	0.041	0.397	0.206	52.85	53.49
	(0.077)	(0.742)	(0.385)	(98.80)	
	Soils of young flood plain: Dakshin Balua series – Fine silty, mixed, hyperthermic Typic Ustifluvents				
P4	0.069	0.484	1.132	76.53	78.21
	(0.088)	(0.619)	(1.447)	(97.85)	
Overall PWM	0.046	0.410	0.469	55.95	56.87
	(0.081)	(0.721)	(0.825)	(98.38)	(100.00)

*Figures within parentheses indicate PWM per cent of total K

(Gangopadhyay *et al.* 2005; Sharma *et al.* 2009). Similar results were reported by Das *et al.* (2000) and Tarafdar and Mukhopadhyay (1986). Further, the higher values of non-exchangeable K in the subsoil might be due to the higher clay and silt content (Table 1) which could easily fix the soluble K (Adhikari *et al.* 1987). The variation in depth wise distribution pattern of non-exchangeable K due to changes in particle size distribution in various layers was also reported by Brar and Sekhon (1987). Relatively, high content of non-exchangeable K in the subsoil of the pedons is an indication of better scope of subsoil contribution of K towards plant nutrition compared to P1 and P3. Almost similar pattern of distribution of non-exchangeable K in some soil profiles of Entisols and Inceptisols has been reported by Singh *et al.* (2006). Based upon PWM-K, the non-exchangeable K in the pedons followed the sequence P4 > P2 > P3 > P1 (Table 3) suggesting maximum non-exchangeable K in soils of young flood plain and minimum in soils of foot hills.

Lattice K

The lattice K in the soils ranged from 36.4 to 86.4 cmol(p^+)kg^{-1} (Table 2) with profile weighted mean of 55.9 cmol(p^+)kg^{-1} contributing 98.4% to total K. In the surface it varied from 50.7 to 83.7 cmol(p^+)kg^{-1}. The mineral K is bound within the crystal structure of soil mineral particles between adjacent tetrahedral layer of micas, vermiculites and intergrade clay minerals (Sparks 1987). The lattice K did not follow any regular pattern down the depth of the pedons. However, the variation was found to be more or less similar to that of non-exchangeable K. The fairly high value of lattice K in the soils is indicative of high K supplying power to crops over a longer period of time especially when K level reach at threshold level, although the availability of this form of K to plants is meager at any specified time. Based upon PWM-K, the lattice K in the pedons followed the sequence P4 > P2 > P3 > P1 (Table 3) suggesting maximum lattice K in soils of young flood plain and minimum in soils of foot hill areas.

Total K

The total K in the soils ranged from 36.9 to 88.2 cmol(p^+)kg^{-1} with profile weighted mean of 56.0 cmol(p^+)kg^{-1}. However, at surface it varied from 51.3 to 85.6 cmol(p^+)kg^{-1}. These results are in agreement with those of Das *et al.* (2000). No definite trend in the distribution of total K was observed down the depth of the pedons similar to the findings of Raskar and Pharande (1997). However, the pattern and quantum of variation down the depth of the pedons is more or less analogous to that of non-exchangeable K and lattice K. Relatively, higher amount of total K in surface soil as compared to the subsoil (except P2 and P4) might be due to the higher contents of clay and silt fractions in these soils (Table 1). Furthermore, in general the higher total K content may be due to the presence of sufficient K bearing primary minerals like feldspar and mica (Ranganathan and Satyanarayanan 1980). Based upon PWM-K, the total K in the pedons followed the sequence P4 > P2 > P3 > P1 (Table 3), suggesting maximum total K in soils of young flood plain and minimum in soils of foot hills.

Inter-relationship between forms of potassium

Significant positive correlation existed between water soluble K and available K (r = 0.716**) similar to the findings of Samadi *et al*. (2010). This might be due to the fact that exchangeable K is usually released into the soil solution from the exchange complex when plants deplete the soluble K, indicating that exchangeable K pool determine the effectiveness of K re-supply, as well as the concentration of K in the soil solution. Water soluble K showed significant and positive correlation with exchangeable K (r = 0.630**) and non-exchangeable K (r = 0.439*) suggesting rapid replenishment of equilibrium between these forms of K. Exchangeable K was positively and significantly correlated with available K (r = 0.993**). The strong significant and positive correlation between non-exchangeable K with lattice K (r = 0.864**) and total K (r = 0.868**) indicates good replenishment of non-exchangeable K from mineral or lattice K. Similarly, significant and positive correlation between lattice K and total K (r = 0.999**) is indicative of the dominant contribution of lattice K to total K (98.4-98.8%) (Patil and Sonar 1993).

Significant and positive correlation between different forms of soil K thus indicates the existence of dynamic equilibrium among the different forms of K, suggesting slow release of reserve K and non-exchangeable K to the available pool upon depletion of available K due to intensive cropping and/or leaching. Furthermore, trend analysis between different K forms unfold a fairly good linearity between total K and non-exchangeable K in the soils under investigation as is evident from the regression equation *viz.* Total K = 32.47 non-exchangeable K + 42.88 ($R^2 = 0.752$).

Conclusions

The results of the present study reveal adequate available K in the soils occurring on different landforms of Borio block, Sahibganj, Jharkhand, developed from Rajmahal trap. Maximum content of non-exchangeable K, lattice K and total K was found in soils of flood plain and minimum in soils of foot hill landform. Significant and positive correlation between different forms of soil K suggests the existence of dynamic equilibrium indicating fair possibility of K replenishment under K-stress. The information generated on the readily available K status as well as the status of reserve K could be important in so far as contribution towards plant available pool of soil K is concerned. Although all the soils have appreciable content of non-exchangeable K, further categorization of non-exchangeable K into so called step-K and constant rate K (CR-K) might provide more insight regarding availability of plant utilizable K from non-exchangeable K under K-stress, especially on a long term basis. High significant positive correlation between lattice K and total K exhibits dominant contribution of the former to the latter. A linear regression equation between total K and non-exchangeable K is proposed that might be helpful for having an estimate of total K content in similar type of soils, keeping away from total K determination involving tedious HF-$HClO_4$ digestion.

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