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Kinetics of Non-exchangeable Potassium Release in Rice-groundnut Cropping System under Alluvial Soils of Odisha, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Non exchangeable K release can very much influence soil K fertility. The experiment was carried out to investigate the amount of non-exchangeable potassium released from Inceptisols with rice-groundnut cropping system and to use various kinetic equations to describe the release. Release rates of non-exchangeable potassium were determined for five different soils collected from rice-

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groundnut cropping system fertilized @ 0 and 40 kg K ha^{-1} over three years. The non-exch K release rate was studied by successive extraction with 0.01M $CaCl_2$ methods. The results show that the proportion of exch.K and non-exch.K to total K varied between 2.76 to 4.95% and 8.39 to 9.95%, respectively. Per cent of clay or silt+clay correlated significantly with water soluble, exch. and non-exch. K. Five mathematical models (elovich equation, power function, parabolic diffusion, first and zero order equation) were used to describe cumulative K release pattern. The elovich and parabolic equation described the K release kinetics satisfactory as evidenced by the highest correlation coefficients and lowest values of standard error of estimates (SEE). The release of Step-K and CR-K was higher in state recommend dose (SRD) than K control which concluded that the SRD of K (40 $kgha^{-1}$) is adequate to sustain the productivity of intensive rice-ground nut cropping system in alluvial soils of Odisha.

Keywords: Mathematical models; non-exchangeable potassium; potassium dynamics; potassium release rate constant.

1. INTRODUCTION

Rice is the principal crop of Odisha state occupying about 72% (43 lakh ha) of gross cropped area during kharif season.Kharif rice followed by groundnut is one of the common cropping sequence practiced in old alluvial soils (Inceptisols) of Odisha. Out of four soil order (Alfisols, Entisols, Inceptisols, and Vertsols), Inceptisols occupy 48% of total geographical area representing older alluvial and mixed red and yellow soils. Soils of Odisha are generally low to medium in available potassium due to presence of kaolinite and illitetype clay minerals in soils.

Several studies showed that application of sub-optimal dose of potassium and unbalanced nutrient usage over years caused mining of potassium [1]. Linquist et al. [2] reported negative K balances not only indicate poor soil health but also environmental degradation and reduced system resilience. Jena et al. [3] observed that the extent of potassium depletion in rice- greengram (laterite soil) and rice-groundnut (alluvial soil) cropping system was 51.0 and 37.0 $kgha^{-1}$, respectively at optimum level of potassium application. However, at super- optimal level (150% NPK) the potassium depletion decreased to 41.0 and 26.0 $kgha^{-1}$in rice-greengramand rice- ground nut cropping system, respectively. Results of two long term experiments at Bhubaneswar with rice-rice cropping system and at Keonjhar with rice- pulse/ oilseed cropping system showed that there was gradual decrease in non-exchangeable potassium over the years and after 20 years,it reached almost 50% of the initial level in 100% NPK treatment [3].

In many production systems in the state, the non-exchangeable potassium meets the crop requirement and sustain the level of production. Therefore, a systematic study on the dynamics of different forms of potassium is necessary with regards to estimation of soil- potassium mining.

The objectives of this study was to investigate the amount of non-exchangeable potassium released from Inceptisols with rice-groundnut cropping system by successive extraction with 0.01M $CaCl_2$ and to use various kinetic equations to describe the release.

2. MATERIALS AND METHODS

Five surface soil samples were collected from a farmer's field trial with rice- groundnut cropping system replicated in five locations namely Nimapada, Pipili, Delang, Kanas and Gope blocks of Puri district in Odisha. The rice and ground nut received potassium @ 0 and 40$kgha^{-1}$. Before layout of the experiment, soil samples from two depths (0- 0.15 and 0.15-0.30m) were collected from five sites of each location, homogenized, air dried and sieved through 2mm sieve and kept for analysis. Soil pH, electrical conductivity were estimated as per standard procedure [4]. Percentage of sand, silt and clay was determined with help of Bouyoucos Hydrometer method [5].

Organic carbon content of soil was determined by wet digestion method of Walkley and Black as outlined by Jackson [4]. Soil samples were also analysed for available N [6], available P [7] and available K [8].

2.1 Estimation of different Forms of Potassium

Processed soil samples were analysed for different forms of K viz. water soluble K [4], Neutral Normal ammonium acetate (NH_4OAC)-extractable K [8], 1N HNO_3- extractable K [9] and total K [4]. The concentration of K was estimated using a flame photometer (Model- Systronics 128).

2.2 Potassium –Release Characteristics

Potassium release pattern was studied by extracting the soil with 0.01M $CaCl_2$ [10].

2.3 Step- K, Constant Rate – K (CR-K) and Cumulative- K

Potassium-supplying parameters such as step K, constant-rate K, and cumulative K were derived as per the procedure of Haylock [11].

2.4 Kinetics of Potassium Release Studies

For kinetics of potassium release studies, non-exchangeable K released with time was fitted using following five equations:

Where, Y is the amount of K released,Y_t is the cumulative K released (mg kg^{-1}) at time t (hours), t, the time of release, Y_0 is the maximum cumulative K released (mg kg^{-1}), and a and b are constants.

Five models were tested by the least-square regression analysis to determine which equation best described the non-exchangeable K release from the soils. Coefficient of determination (R^2) were obtained by least square regression of measured vs.predicted values. Standard error of the estimate (SEE) was calculated by

$$SEE = (\text{Summation } (q-q^*)^2 /n-2)^{½}$$

Where, q and q* represent the measured and calculated amounts of non-exchangeable K in soil at time t, respectively, and n is the number of data points evaluated. The rate constants of K release from soils in different media of extraction were calculated on the basis of these models.

3. RESULTS

3.1 Soil Properties

The data presented in Table 2 showed that the soils of different sites are non-saline, acidic in reaction and pH ranged from 4.86 to6.40 in surface soils might be due to intensive cropping and continuous application of acid forming fertilisers over years. The textural class ranged from sandy loam to silt clay. Clay content in all sites was lower than 30% except Kanas (54-58%). Organic carbon content in surface soils was higher than subsurface soils due to accumulation and decomposition of left over crop residues after harvest of crops. Low available N status was associated with high N removal by rice-groundnut cropping system practiced by the farmers in the locality. The soils were medium in available in P.

3.2 Forms of Potassium

Small amount of water soluble k was present in all sites which ranged from 3.6 to 16.3 $mgkg^{-1}$ in surface soils and 4.5 to 15.4 $mgkg^{-1}$ in subsurface soils (Table 2). Water soluble K was higher in surface soils than subsurface soils which might be due to capillary movement of potassium from lower depth to upper portion reported by Charankumar et al. [14].

Exchangeable K content is generally associated with soil texture and clay content. It is higher in fine texture soils than coarse texture. In present study, exchangeable K content ranged from 75.3 to 80.9 $mgkg^{-1}$ in silt clay, 46.4 mg kg^{-1} in clay loam,18.2 to 28.6 $mgkg^{-1}$ in loam,23.5 to 44.1 $mgkg^{-1}$ in silt clay loam and 19.4 $mgkg^{-1}$ in sandy loam. Highest amount of exchangeable K was recorded in Kanas with highest amount of clay content (54-58%) whereas, the reverse trend was recorded in Delang. Several workers reported that higher amount of exchangeable K in surface soil was resulted due to intensive weathering of minerals, addition of potassic fertilizer and release of K from organic matter [15]. Non-exchangeable K content ranged from 32.4 to236.3 $mgkg^{-1}$. Dominant clay minerals like illite and vermiculite influence non-exchangeable K. Lattice K content in all sites followed the similar as of exchangeable and non-exchangeable K.

Table 3 presents different forms of K on soil texture basis. In general, all forms of K is higher in fine texture soil than coarse texture. The content of all forms of K was higher in silt clay and lowest in sandy loam. On soil texture basis, the magnitude of all forms of K are in decreasing order of silt clay> clay loam> silt clay loam> loam> sandy loam.

Further, the data revealed that water soluble K constitute 0.6 to1.10% of total K. The results of several studies indicated that proportion of water soluble K to total K varied from 0.03-0.18% in surface soil of groundnut- groundnut cropping system of Andra Pradesh [15].

Proportion of exchangeable K to total Kvaried between 2.76 to 4.95%, being highest in sandy loam and lowest inclay loam. However, Charankumar and Munaswami [15] reported exchangeable K to total K varied from 0.24 to 2.02% in surface soils of fallow –paddy cropping system of Andra Pradesh.

Percentage of non-exchangeable K to total K varied between 8.39 to 9.95% which also reported by Charankumar et al*.* [14] that the proportion of non-exchangeable K to total K varied between 2.23 to 5.08% in surface soils of Andra Pradesh and lattice K to total K from 84.97 to 88.06% also reported by Charankumar et al*.* [14].

3.3 Relationship between Soil Separates and different Forms of K

Per cent of sand significantly correlated with WSK/ exch. K/ non-exch. K with R^2 values ranging from 0.78 to 0.89. Different forms of K decreased with increasing sand per cent. Significant relationship exists between silt per cent with WSK, but non-significant with exch.K and non-exch. K. The per cent of clay or silt+clay significantly correlated with different forms K (Table 4). Similar observation reported by Zareian et al*.* [16].

Further, the data showed that the relationship between WSK vs. exch.K or non-exch.K and exch.K vs. non-exch.K were highly significant (Fig. 1a to 1c). Similar observations were reported byDhakad et al. [17].

3.4 Kinetics of Potassium Release (Cumulative K, Step K and CR-K)

The effects of potassium fertilization in rice-groundnut cropping system over three years on various non-exchangeable K-release parameters such as step K, constant-rate K, step K / constant K ratio and cumulative K release are presented in Table 5.

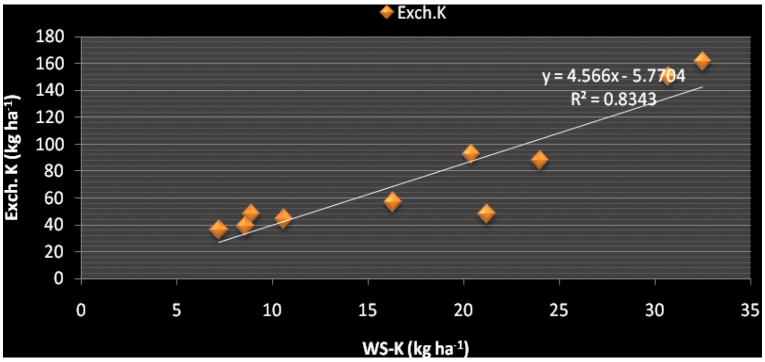
Plots of cumulative non-exch. K release are shown in Figs. 2- 3. In allsites, the magnitude of K release in K_{40} was higher than K_0 treatment. Cumulative K released after 700 hr in 0.01M $CaCl_2$ ranged from 920 to 1508 mgkg^{-1} in K_0 and 1159 to 1788 mgkg^{-1} in K_{40}. It is observed that the cumulative K released in all sites was higher in K_{40} than K_0 might be due to addition of potassic fertilizer to each crop in K_{40} treatment which maintained the soil K status.

Plots of cumulative K releasedconsist of two segments in all soils. The first segment of the curve showed an initial rapid phase followed by a slow phase of K release. The first curvilinear part indicated rapid K release from edge sites whereas, the second linear part indicates the K release from internal sites.The first segment of the curves, which comprised about 285 hours in 0.01 M $CaCl_2$ method represent the so-called "initial rate" and varies with the soil. This first segment is believed to represent the rapid K release from the soil. The second segment following a transition stage is the immediate long-term release rate representing upto 650 hrs in 0.01 M $CaCl_2$method of K release. This second segment is known to be crucial for the replenishment of the labile soil K. The initial K release rates were higher than the rates observed in second segment, with about more than 80% of the total K release occurring during the first segment. The cumulative K release plot shows a pattern similar to that demonstrated by Zareian et al*.* [16].

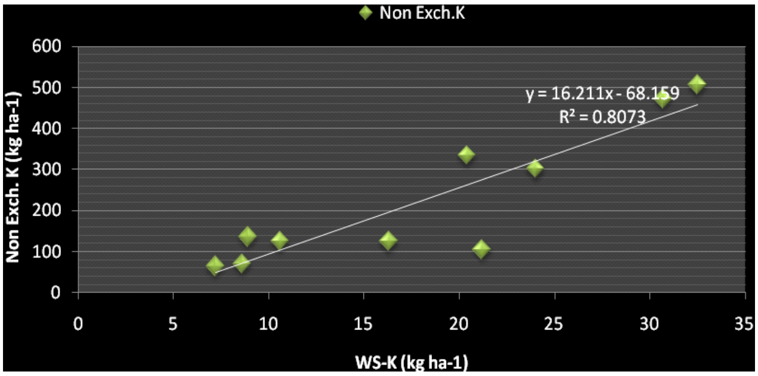
The cumulative non-exchangeable K release was 768 to 1408 mg kg^{-1}0.01 M $CaCl_2$ extraction method. Rahmatullah and Mengel [18] indicated that in a root–soil relationship, interlayer K is not predominately released by direct cationexchange. In 0.01M $CaCl_2$ method, the greater values of release rate in the initial period could be due to exchange of K^+ by Ca^{++} on surface sites of clay structure. Once K^+ is exchanged on these sites, further exchange of K^+ by Ca^{++} would be slower, as the size of hydrated Ca^{++} (4.3 A^0) is larger than hydrated K^+ (3.3 A^0). This can be attributed to non-exchangeable K^+ in the soils being more tightly retained due to prevalence of micaous minerals. Vermiculite, mica and illite are the clay minerals that have the greatest capacity to fix K^+. The release of non-exchangeable K is thought not to be the result of dissolution of primary K bearing minerals but is actually an exchange reaction. This exchange is too slow to be measured with normal methods of determining exchangeable K. When this slow exchange occurs in the interlayers of clay minerals such as mica, the replacing ion must first enter the unexpanded interlayer without its hydration shell. Then or simultaneously the interlayer will expand upon hydration of these ions allowing fixed or trapped K^+ to hydrate and slowly diffuse to exchange sites on outer parts of the clay particle.

Table 1. Kinetic equations of potassium release studies

Kinetic equation	Expression form	Reference(s)
Power function equation	lnY = lna + b lnt	Havlinet al. [12]
Elovich equation	Y = a + b lnt	Havlin et al. [12]
Parabolic diffusion equation	Y = a + *b t½*	Havlin et al. [12]
First-order equation	$\ln(Y_0 - Y_t) = a - bt$	Martin and Sparks [13]
Zero-order equation	$(Y_0 - Y_t) = a - bt$	Martin and Sparks [13]



(a)



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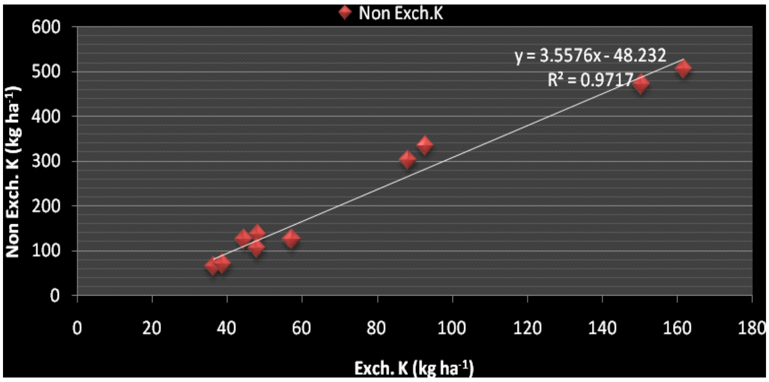


(c)

Fig. 1. Relationship between (a) WS K vs. exch. K (b) WS K vs. non-exch. K (c) exch. K vs. non-exch. K

The Step K provides an estimation of mineral K that is potentially available on due course of time [11] and the content in the control plot varied from 768 to 1318 mg kg $^{-1}$, whereas in state recommended dose of K plots it varied from 988 to 1408 mg kg $^{-1}$.

Table 2. Initial physico-chemical properties and nutrient status of soil of experimental sites

Replication/Sites	Soil depth (cm)	Initial soil physico-chemical properties									Initial Soil nutrient status				
											K-status (mg kg^{-1})				
		pH (1:2.5)	EC (dSm^{-1})	Sand (%)	Silt (%)	Clay (%)	Textural class	OC (%)	Avl. N (kg ha^{-1})	Avl. P (kg ha^{-1})	Water Soluble K	Exch. K	Non-Exch. K	Lattice K	Total K
R_1 (Nimapada)	0-15	5.05	0.005	58.6	22	19.4	Loam	0.73	43.7	4.6	8.2	28.6	62.4	537.1	636.3
	15-30	6.20	0.003	48.6	24	27.4	Clay loam	0.43	38.1	5.3	10.2	46.4	167.4	1458.4	1682.4
R_2 (Pipili)	0-15	6.40	0.003	62.0	20	18.0	Loam	0.58	42.0	6.3	3.6	18.2	32.4	377.1	431.3
	15-30	6.53	0.005	62.0	18	20.0	loam	0.43	39.2	4.9	4.5	24.1	68.3	734.1	831.0
R_3 (Delang)	0-15	4.86	0.001	74.6	12	13.4	Sandy loam	0.45	43.1	8.5	4.3	19.4	35.2	333.2	392.1
	15-30	6.26	0.002	70.6	14	15.4	Loam	0.26	34.7	6.7	5.3	22.3	62.8	703.4	793.8
R_4 (Kanas)	0-15	5.47	0.002	20.0	26	54.0	Silty clay	0.54	53.2	5.6	16.3	80.9	235.8	2462.2	2795.2
	15-30	5.81	0.003	14.0	28	58.0	Silty clay	0.41	49.3	10.2	15.4	75.3	236.3	2420.8	2747.8
R_5 (Gope)	0-15	5.60	0.005	42.6	32	25.4	Silty clay loam	0.73	42.0	8.3	10.6	23.5	52.5	449.0	536.6
	15-30	5.90	0.002	44.6	34	21.4	Silty clay loam	0.50	41.5	6.0	12.0	44.1	151.3	1371.9	1579.3

Table 3. Forms of Potassium (mg kg^{-1}) on texture basis

Texture	No. of samples	WSK	Exch.K	Non-Exch.K	Lattice. K	Total K
Loam	4	5.4 (0.8)	23.3 (3.5)	56.5(8.39)	587.9(87.31)	673.1
Clayloam	1	10.2(0.6)	46.4(2.76)	167.4(9.95)	1458.4(86.69)	1682.4
Silt Clay	2	15.9(0.6)	78.1(2.82)	236.1(8.52)	2441.5(88.06)	2771.6
Sandy Loam	1	4.3(1.1)	19.4(4.95)	35.2(8.98)	333.2(84.97)	392.1
Silt Clay Loam	2	11.3(1.1)	33.8(3.20)	101.9(9.64)	910.5(86.06)	1057.5

Note: Figures in bracket indicates percent to total K

Table 4. Relationship between sand/silt/clay/clay+silt with different forms of K

Soil separate (%)		Different forms of K		
		Water Soluble K	Exchangeable K	Non-exchangeable K
Sand	Equation	Y = -0.432x+39.56	Y = -2.089x+180.5	Y = -7.280x+586.5
	R^2	0.893**	0.834**	0.777**
Silt	Equation	Y = 0.957x-3.979	Y = 3.160x+3.902	Y = 11.78x+46.71
	R^2	0.565**	0.246	0.262
Clay	Equation	Y = 0.508x+4.182	Y = 2.768x+1.190	Y = 9.483x-34.06
	R^2	0.750**	0.889**	0.801**
Clay+silt	Equation	Y = 0.432x-3.691	Y = 2.089x-28.37	Y = 7.280x-141.5
	R^2	0.893**	0.834**	0.777**

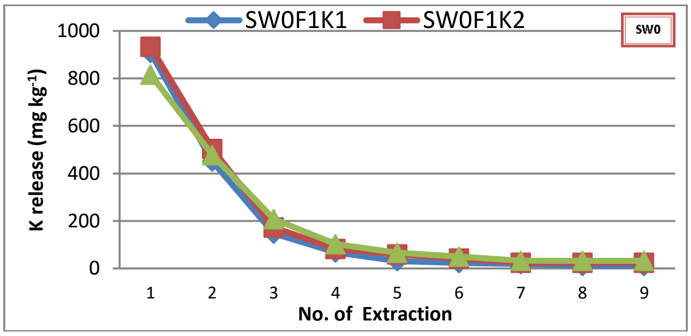


Fig. 2. Potassium release in K0 treatment

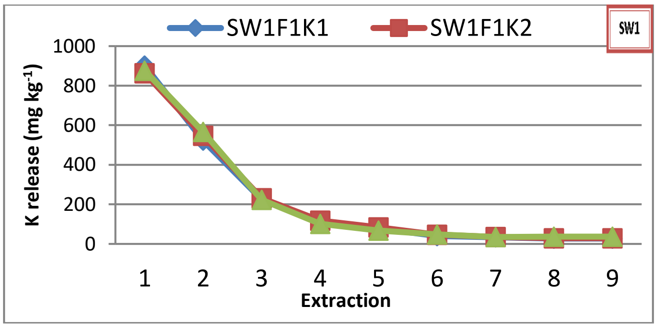


Fig. 3. Potassium release in K_{40} treatment

Haylock [11] referred CR-K as of limited solubility and releasing K at constant rate. The constant rate K in different sites ranged from 8 to 12mg kg^{-1} in K_0 whereas, 9 to 20 mg kg^{-1} in K_{40}, respectively (Table 5). However, there were differences in constant K rate among different sites under various K fertilizer treatments, as it was related to mineralogical composition of soil or soil textural difference. Similar observation observed by Srinivasaraoet al. [19].

Table 5. Release of potassium (mg kg^{-1}) in K_0 and K_{40} treatments

Site	K_0			K_{40}		
	CR-K	Total Cumulative K	Total Step K	CR-K	Total Cumulative K	Total Step K
Nimapada	8	1068	916	10	1252	1062
Pipili	10	1116	926	10	1426	1236
Delang	12	1201	973	14	1508	1242
Kanas	8	920	768	9	1159	988
Gope	10	1508	1318	20	1788	1408

3.5 Descriptions of Potassium Release by Kinetics Models

Five different kinetic models were used to describe non-exchangeable K release pattern from the soils. Results of the statistical analysis obtained by plots, which fits between the models and the experimental data, are reflected by the Correlation Coefficients of Determination (R^2) and the Standard Errors of the Estimates (SEE) for the kinetics models.

The pattern of successive extraction of K from soils in 0.01 M $CaCl_2$ solution are presented in Figs. 4-8. There was a wide variation in the cumulative K released among the soils. The differences in K release among the soils could be attributed to the differences in contents of clay and silt, and the types of clay minerals. Based on the coefficients of determination (R^2) and standard error of the estimate (SEE) values (Table 6), the elovich and parabolic diffusion equations described the release of K fairy well. The elovich equation with higher R^2 values (0.956-0.975) and the lower SEE values (7.13-14.02 mg kg^{-1}) and parabolic diffusion (R^2 = 0.912-0.955, SEE = 8.99-20.35 mg kg^{-1}) models could describe well K release K_0 treatment. Similarly in the state recommended dose of K treatment, the elovich (R^2= 0.958-0.968, SEE = 8.98-15.71 mg kg^{-1}) and parabolic diffusion (R^2= 0.908-0.939, SEE = 14.22-22.60 mg kg^{-1}) equations with higher R^2 values and the lower SEE and could describe well the K release pattern. Although, the power function equation had higher R^2 values (0.955-0.970) but due to higher SEE, could not be compared with elovich and parabolic equations. The First order and Zero order equations could not describe K release as compared to other models in both the treatments. Comparatively lower R^2 values, and particularly the relatively high values of the SEE of the estimates of the zero order model provide a strong case for its non-fit.Similar observations recorded for the state recommended dose of K treatment (Table 7).

These findings are in good agreement with the results obtained by Zareian et al. [16]. This indicates that the rate of K release from these soils is a function of the reciprocal of time under equilibrium conditions and is a diffusion-controlled exchange reaction from the mineral matrix of weathered periphery. Successful presentations of a parabolic diffusion equation for non-exchangeable K release from soils were earlier reported for some soils of India and by Srinivasarao et al. [20] for differentially manured soils of India.

3.6 Non Exchangeable Potassium Release Constants (a and b)

The release rate constants a and b of each model represent the intercept and the slope of the linear curves resulting from plotting the released K^+ vs. time (Table 7). The constant *b* (also referred to as rate constant, k) described the release rate of the non-exchangeable K^+. The *b* values are known to correlate well with crop K released from the non-exchangeable K phase.

Out of the five models used, the fit of the data to the power function equation yielded a straight line, where the constant *b*, which also represents the slope and can be used as an index of K release rate, ranged from 0.424 (Delang) to 0.498 (Gope) mg kg^{-1} h^{-1} in K_0 and 0.465 (Pipili) to 0.493 (Delang) mg kg^{-1} h^{-1} in K_{40}. The *b* values in power function equation were less than 1 for all soils, indicating that the K release rates decreased with time. It is also evident that the power function equation which displayed the third highest fit, also showed a rate constant (K) for its model indicative of a healthy K release rate typical for non-fixing clays. In addition, successful description of K release by the power function equation was also reported byZareian et al. [16].

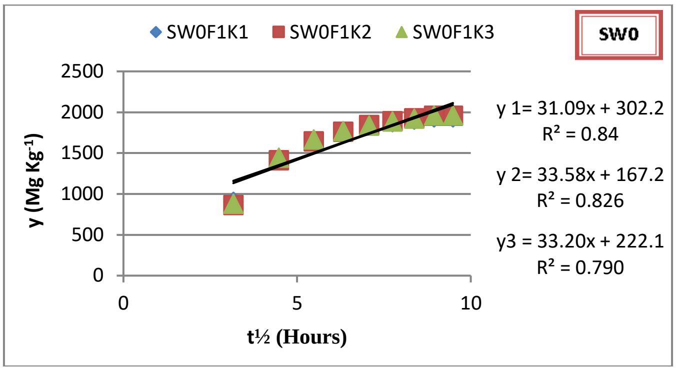
The elovich equation was also fitted to the cumulative K, where the constant *b*, represents the release rate. It ranged from 190.6 (Kanas) to 314.3(Gope) mg kg^{-1} h^{-1} in K_0and246.7 (Kanas)

Table 6. Coefficients of determination (R^2) and Standard Errors of the Estimate (SEE) of five kinetic models for K release of different sites by 0.01M $CaCl_2$ extraction at K_0 and K_{40}

Site	Equations									
	Power		Elovich		Parabolic		First order		Zero order	
	R^2	SEE	R^2	SEE	R^2	SEE	R^2	SEE	R^2	SEE
K_0										
Nimapada	0.979	167.31	0.959	9.52	0.955	10.49	0.920	167.25	0.848	136.15
Pipili	0.962	183.01	0.975	7.13	0.930	13.69	0.924	182.96	0.801	149.24
Delang	0.966	179.49	0.972	7.79	0.927	13.06	0.949	145.81	0.797	179.42
Kanas	0.978	141.06	0.964	7.29	0.951	8.99	0.922	114.13	0.839	141.05
Gope	0.958	230.44	0.956	14.02	0.912	20.35	0.960	192.24	0.778	230.45
K_{40}										
Nimapada	0.970	197.15	0.967	9.72	0.939	14.22	0.925	197.07	0.819	160.84
Pipili	0.955	233.00	0.964	12.05	0.908	20.16	0.953	232.94	0.769	192.90
Delang	0.963	231.64	0.963	12.20	0.928	18.51	0.931	231.62	0.801	190.98
Kanas	0.964	185.05	0.968	8.98	0.929	14.43	0.936	185.01	0.800	151.95
Gope	0.961	266.16	0.958	15.71	0.916	22.60	0.951	266.11	0.784	220.87

Table 7. Parameters of the five models used to describe K release kinetics in soils of different sites by 0.01M $CaCl_2$ extraction at K_0 and K_{40}

Site	Mathematical models (mg kg^{-1} h^{-1})									
	Power		Elovich		Parabolic		First order		Zero order	
	a	b	a	b	a	b	a	b	a	b
K_0										
Nimapada	3.820	0.485	-563.4	232.2	75.19	37.25	7.664	-0.011	579.8	-1.127
Pipili	4.060	0.459	-523.5	236.8	141.00	37.18	7.585	-0.011	564.0	-1.107
Delang	4.240	0.424	-457.7	221.9	165.30	34.83	7.477	-0.011	523.4	-1.037
Kanas	3.748	0.468	-446.6	190.6	79.86	30.44	7.392	-0.011	472.3	-0.918
Gope	4.064	0.498	-747.5	314.3	134.60	49.34	7.849	-0.012	729.6	-1.464
K_{40}										
Nimapada	4.023	0.478	-622.6	265.9	116.9	42.14	7.758	-0.011	643.7	-1.263
Pipili	4.267	0.465	-670.6	302.0	181.9	47.11	7.771	-0.012	694.9	-1.392
Delang	4.098	0.493	-751.5	316.0	131.1	49.86	7.940	-0.012	752.1	-1.487
Kanas	3.967	0.477	-569.0	246.7	121.5	38.86	7.617	-0.011	586.6	-1.158
Gope	4.296	0.483	-833.3	357.4	168.5	56.18	8.055	-0.012	833.0	-1.669



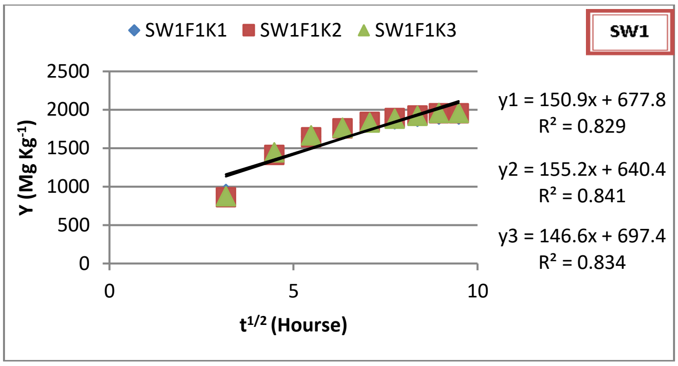
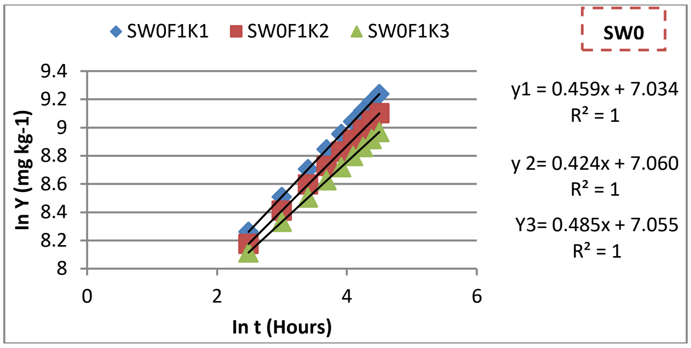


Fig. 4. Power function kinetics of non-exchangeable K released in K_0 and K_{40} treatments



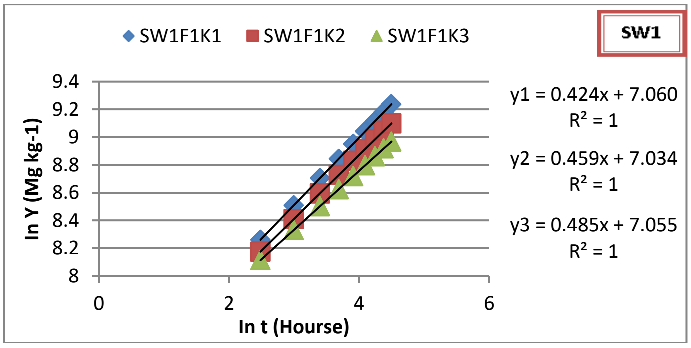


Fig. 5. Elovich equation kinetics of non-exchangeable K released in K_0 and K_{40} treatments

and 357.4 (Gope)mg kg^{-1} h^{-1} in K_{40}. The differences in *b* value indicated that K supplying power of the soils was different. Successful presentations of K release from soils with the elovich equation has been reported by Hosseinpur and Safari Sinegani [21].

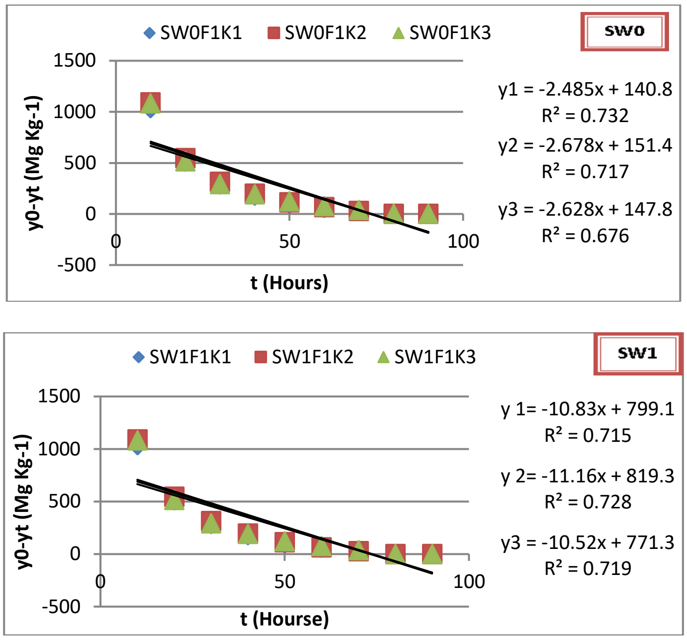


Fig. 6. Parabolic diffusion equation kinetics of non-exchangeable K released in K_0 and K_{40} treatments

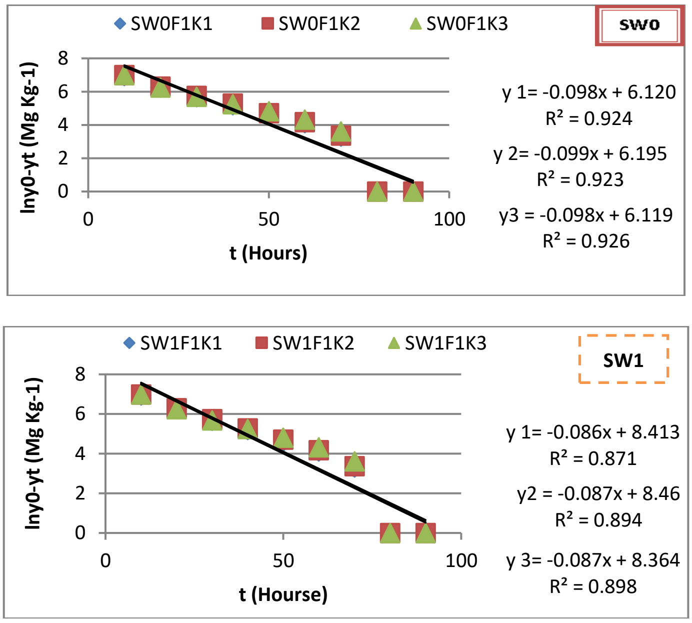


Fig. 7. First order equation kinetics of non-exchangeable K released in K_0 and K_{40}

This may present a strong indication that the clay fraction in study soils has a high capacity to release K to compensate for crop uptake. The K release rates in parabolic diffusion equation ranged from 30.44 (Kanas) to 49.34 (Gope) mg kg^{-1} $h^{-1/2}$ in K_0 and 38.86 (Kanas) and 56.18 (Gope) mg kg^{-1} $h^{-1/2}$ in K_{40} treatments. A linear plot of K release *versus* $t^{1/2}$ showed that the parabolic diffusion equation adequately described the K release process, indicating that the diffusion of K out of the mineral matrix or weathered periphery may be a rate-controlling process which also successful presentations of K release from soils with a parabolic diffusion equation were earlier reported by Lu et al. [22].

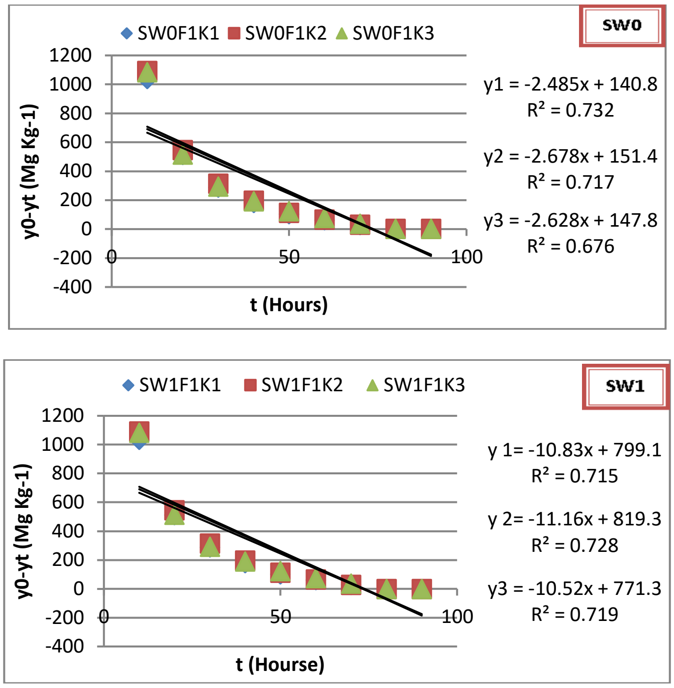


Fig. 8. Zero order equation kinetics of non-exchangeable K released in K_0 and K_{40}
Note: K_0 = SWO and K_{40} = SW1

The b values of first order and zero order equations were too lower, indicating that non-fit to describe K release. The rate constants of the five models showed larger values for the state recommended dose of K treatments compared with control treatments.

4. CONCLUSION

Different forms of K (WSK, exch.K, non-exch.K and lattice K) were higher in fine texture silt clay than sandy loam. Per cent of clay or silt+ clay significantly correlated with different forms of K. Cumulative K release was more in state recommended dose than in control treatment. The cumulative curves showed two segments that are typically associated to K release studies. The first segment represent the so-called "initial rate", and varies with the soil. The second segment following a transition stage is the immediate long-term release rate.Step K content varied from 768 to 1318 mg kg $^{-1}$ in control and 988 to 1408 mg kg $^{-1}$ in state recommended dose. Release of K at constant rate (CR-K) ranged from 8-12 mg kg^{-1} in control and 9-12 mg kg^{-1} in SRD (40 kg K ha^{-1}). Based on the R^2 value, SEE (Standard Error of Estimate) and b (slope of linear curve) value, the elovich equation and parabolic diffusion model described the kinetics of K release significantly as compared to power function, zero order and first order equations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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