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Dynamics of potassium fractions under submergence in characteristic sandy clay and loamy sand rice soils of Kerala

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Abstract
A laboratory incubation study was carried out at the College of Agriculture, Vellayani to monitor the dynamics of native as well as applied K in the two representative soil types - lateritic alluvium of Pattambi (Kandiaqult) and *Onattukara* sandy soils (Quartzipsamment) as influenced by a flooded moisture regime. The experiment was carried out at two levels of K – 0 and 45 kg K_2O ha^{-1}. Wet soil samples were drawn at periodic intervals and analysed for water soluble, exchangeable, available, nitric acid soluble, fixed and lattice bound fractions of potassium. A gradual decrease in water soluble K fraction was observed after 15 days of submergence in Pattambi soils and after 20 days in *Onattukara* soils. *Onattukara* soils recorded higher values of water soluble K fraction as compared to Pattambi soils. But exchangeable and available K fractions were higher in Pattambi soils than in *Onattukara* soils. The decrease in available K with submergence observed in Pattambi soils is attributed to potassium fixation in the soil which is not noticed in *Onattukara* soils. At higher level of added K statistically significant increase in the HNO_3 – K fraction was observed on the 50^{th} day of submergence in Pattambi soils. Significant increase of fixed potassium was observed after 30 days of submergence (284.4 mgkg-1) and then again on 50 days of submergence (290.6 $mgkg^{-1}$) in Pattambi soils. There was no significant change in the fixed potassium fraction in *Onattukara* soils. Neither the added K nor the period of submergence could bring about a change in the clay mineral lattice which accommodates the lattice K fraction.

Keywords: Water soluble K, exchangeable K, available K, HNO_3 - K, potassium fixation

Introduction
Potassium is one of the earliest plant nutrients recognised by Justus von Liebig in 1840 who proved its essentiality for the growth and development of plants. Being an alkali metal of high solubility it is found to be a limiting plant nutrient in the soils of humid tropical areas. It is doubtful whether there is any other element which acclaims as much importance as that of K because of its involvement in more than 60 enzymatic reactions within the plant. The extent of rice response to K application is less than that observed for N and P, although above ground K content of rice is equal to or greater than the plant N content and greater than all other essential nutrients (Singh and Singh, 2017) [1]. Reports from various rice research stations in Kerala have revealed that there exists a high variability in the response of fertiliser K with respect to rice yields. Though there is differential response in different high yielding varieties it is seen that with the same variety there exists marked variation in yield in different wetland soil groups of the state. Recent studies on the natural and manmade wetlands of Kerala have shown that the spatial and temporal variability in the physico-chemical and mineralogical characteristics are highly significant. Proper assessment of potassium availability is a pre-requisite for soil fertility evaluation, correct interpretation and appropriate use of fertilisers. With this objective, a laboratory incubation study was carried out at the College of Agriculture, Vellayani to monitor the dynamics of native as well as applied K in the two representative soil types as influenced by a flooded moisture regime. The two major wetland rice soils selected were lateritic alluvium of Pattambi (Kandiaqult) and *Onattukara* sandy soils (Quartzipsamment).

Materials and methods
Surface soil samples (0-20 cm) were collected from RARS, Pattambi and ORARS, Onattukara. The basic soil analysis of the two wetland soils was done as per standard procedures. The experiment was carried out at two levels of applied K – 0 and 45 kg K_2O ha^{-1}, each with three replications. Soil samples equivalent to 500 g of oven dry soil were taken in plastic containers from the bulk sample maintained in field condition.

These samples were then flooded with water so as to maintain a standing level of 5 cm. Potassium was applied in the form of potassium chloride as per the treatment levels. The soil in each container was stirred with a thick glass rod to ensure uniform mixing. The buckets were then placed for incubation for a period of two months at room temperature on a level surface in the laboratory. Wet soil samples were drawn from each incubation bucket at intervals of 0, 10, 15, 20, 30, 40, 50 and 60 days. These samples were analysed for water soluble, exchangeable, available, nitric acid soluble, fixed and lattice bound fractions of potassium. Water soluble K was estimated by extraction with distilled water. Available K was determined by flame photometry from the neutral 1*N* NH_4OAC extract. Exchangeable K was computed as the difference between available K and water soluble K. The HNO_3 extractable K was determined by flame photometry (Wood and De Turck, 1941) [2]. Non – exchangeable /fixed K was estimated by subtracting available K from HNO_3 extractable K. Total K was determined by flame photometry as standardised by Pratt (1965) [3]. The lattice K was calculated as the sum of 1*N* HNO_3(boiling) and extractable K deducted from the total soil K. Statistical analysis was carried out by adopting standard methods described by Panse and Sukhatme (1967) [4]. Standard error was calculated by using Microsoft Excel 2013 (Microsoft Corporation, Redmond, USA).

Results and discussion

Analysis of surface soil samples

Basic soil analysis of Pattambi and *Onattukara* soils was done (Table 1). Significant difference existed with regard to the soil textural class, pH, organic matter and P_2O_5 content between the two soils.

Table 1: Physico-chemical parameters of the characteristic sandy clay and loamy sand wetland acidic rice soils of Kerala

	Sandy clay	Loamy sand
Coarse sand (%)	32.15 ± 1.14	77.16 ± 2.18 **
Fine sand (%)	10.26 ± 1.15	10.65 ± 0.61
Silt (%)	8.25 ± 0.37	4.25 ± 0.12
Clay (%)	49.0 ± 3.52 **	11.75 ± 0.29
pH (water) (1:25)	5.4 ± 0.4 *	5.0 ± 0.5
EC	0.04 ± 0.01	0.02 ± 0.01
OC (%)	1.76 ± 0.15 **	0.81 ± 0.22
Available N (kg ha^{-1})	341.36 ± 48.87	282.68 ± 31.09
Available P (kg ha^{-1})	49.25 ± 15.90	121.34 ± 8.58 **
Available K (kg ha^{-1})	161.82 ± 14.50	137.46 ± 33.88

Data are average of ten replicates ± standard deviation (SD).
$t_{(df\,9)}$ = 2.821, $p \leq 0.01^{**}$; 1.833, $p \leq 0.05$*

Water soluble potassium

Results of the incubation study revealed that submergence for 60 days caused significant increases in water soluble K fraction without fertilisation whereas a significant decrease was observed under fertiliser K addition (Table 2). At zero levels of K, there was a general trend of a progressive increase in the water soluble K fraction in both the rice soils studied, with advancement in the period of submergence. This may be due to the formation of free cations, consequent to the reduction process set in by submergence, which substitutes the exchangeable K from the exchange sites, ultimately leading to an increase in the water soluble K content of soil solution. Upon water logging, the amount of water extractable K increases as a result of exchange reaction due to increase in Fe^{+2} and Mn^{+2} (Ponnamperuma, 1972) [5]. There was a significant decrease in water soluble K fraction from 10 days of submergence in the acidic clay rice soils where K was added. A similar decrease in water soluble K fraction was observed in acidic sandy loam soils too where K was added, statistical significance in the decrease being evident only after 15 days of submergence. Thus submergence had a depressing effect on the water soluble K fraction of fertiliser added soils. Hebsur and Satyanarayana (2001) [6] has reported that water soluble K decreased with an increase in the time of incubation. Rajeevana *et al.* (2017) [7] also observed a decrease in water soluble potassium content after 14 days of incubation in fertiliser applied soils. However, the magnitude of water soluble K fraction in sandy loam rice soils was higher as compared to the clay rice soils. This may be attributed to the high exchange capacity resulting from high organic carbon (1.76%) and clay content (49%) of the clay rice soils which retained more of added K in the exchange sites rather than in solution as compared to the sandy loam rice soils.

Table 2: Temporal variation in water soluble K fraction of clay and loamy sand wetland acidic rice soils under submergence with and without applied potassium ($mgkg^{-1}$)

Incubation period (days)	Sandy clay		Loamy sand	
	K_0	$K_{45\ kg\ ha^{-1}}$	K_0	$K_{45\ kg\ ha^{-1}}$
	mgkg-1			
0	15.43 ± 0.27 ^{f}	47.52 ± 0.08^{a}	11.83 ± 1.04^{b}	51.45 ± 1.10^{a}
10	15.15 ± 0.08 ^{g}	42.62 ± 0.11^{b}	11.78 ± 0.11 ^{b}	48.24 ± 1.00 ^{b}
15	15.34 ± 0.17 ^{f}	39.41 ± 0.09 ^{c}	11.81 ± 0.12^{b}	47.57 ± 1.03 ^{b}
20	15.82 ± 0.09^{e}	38.32 ± 0.07^{d}	11.94 ± 0.23 ^{b}	44.76 ± 1.47 ^{c}
30	16.44 ± 0.10^{d}	33.52 ± 0.13^{e}	12.17 ± 0.09 ^{b}	41.59 ± 0.45 ^{d}
40	16.83 ± 0.09 ^{c}	29.63 ± 0.10 ^{f}	12.64 ± 0.11^{a}	39.62 ± 0.66 ^{e}
50	17.34 ± 0.10 ^{b}	26.51 ± 0.09^{g}	12.72 ± 0.08^{a}	37.53 ± 0.29 ^{f}
60	17.71 ± 0.28 ^{a}	24.82 ± 0.08^{h}	12.89 ± 0.20 ^{a}	36.38 ± 0.23 ^{g}
ANOVA	S	S	S	S

Means sharing similar letter(s) at different periods within a treatment do not differ significantly at $P \leq 0.05$. Data are average of seven replicates ± standard deviation (SD).

Exchangeable Potassium

Temporal variation in the exchangeable K content was marked by a perceptibly significant increasing trend in both the sandy clay as well sandy loam rice soils (Fig.1). The highest exchangeable K content was recorded after 30 days of incubation in both these soil types under continuous submergence. The addition of fertiliser potassium has resulted in the increased exchangeable K content in both soils, thus supporting the existence of a dynamic equilibrium between different forms of K, especially water soluble and exchangeable K. This observation is in concurrence with the reports of Assimakopoulos (1994) [8]., Yadav (1999) [9].

There occurred a 32.77% enhancement in the exchangeable K fraction of the sandy clay rice soils on 60 days after submergence as compared with the 41.55% enhancement in the sandy loam rice soils. However the magnitude of the mean exchangeable K in the sandy clay rice soils during the 60 day incubation period exceeded that of the sandy loam soils by 30%. The increase in magnitude of exchangeable K observed in sandy clay rice soils upon submergence is due to the conversion of water soluble form to exchangeable form at a higher magnitude as compared to sandy loam soils owing to its high exchange capacity. Joseph (1993) [10] reported that the exchangeable K content on incubation increased up to the 60th day, maintained the same level until the 75th day and then decreased. The increase in exchangeable K on submergence observed in both soils at higher dose of K is due to the conversion of available form to exchangeable form. This high magnitude of increase in clay rice soils is relevant from the potassium nutrient management point of view. Added K is seen retained in the exchange complex, thus not only preventing leaching loss of added potassium from the soil but also extending the availability of potassium for a longer period due to the existence of the dynamic equilibrium between exchangeable and water soluble forms.

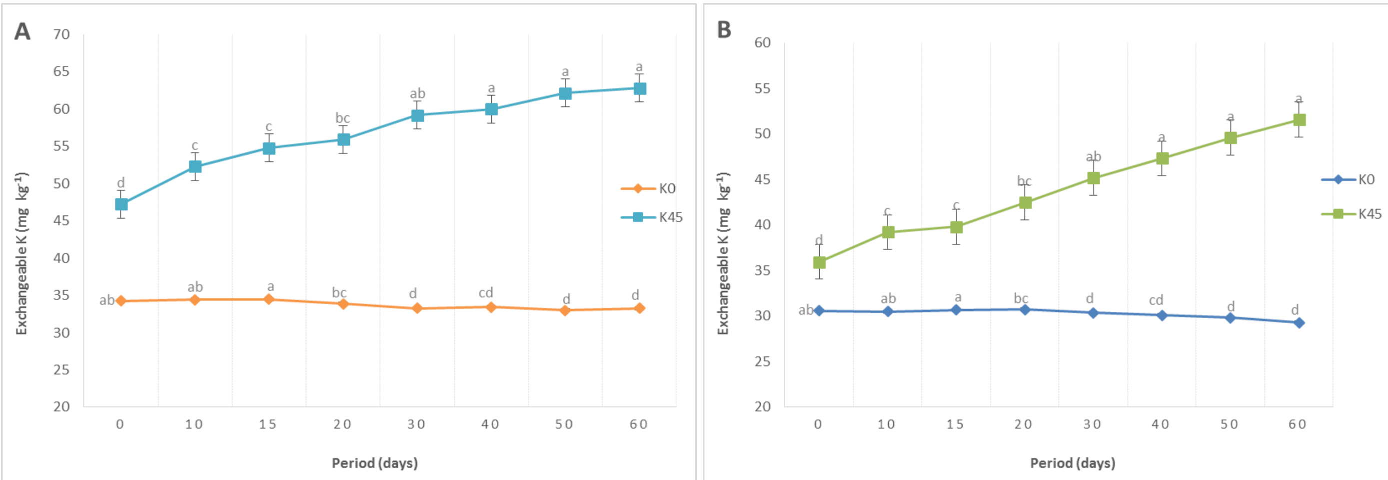

Fig 1: Temporal variation in exchangeable K fraction of (A) clay and (B) loamy sand wetland rice soil under submergence. K_0: without K application; K_{45}:K applied @ 45 kg ha^{-1}. Means (± standard errors) within the same graph followed by different letters are significantly different at $p < 0.05$.

Available potassium

The dynamics of available K as revealed by the incubation study (Table 3) shows that in sandy clay rice soils the mean available K fraction (92 mg kg^{-1}) was significantly high at 45 kg ha^{-1} of K compared to that without added K (50 mgkg^{-1}). A significant decline in available K was noticed in the sandy clay rice soils with added K from 40 days of incubation which continued up to 60 days of incubation. In sandy loam rice soils also, the available K content with added potassium (87 mgkg^{-1}) and at zero level of added potassium (42 mgkg^{-1}) differed significantly. However the temporal variation of available K without added potassium in these soils did not exhibit any significance and maintained more or less static nature throughout the incubation period. The decrease in available K with submergence observed in sandy clay rice soils is attributed to fixation of potassium in the soil which is not noticed in the sandy loam soils.

Table 3: Temporal variation in available K fraction of clay and loamy sand wetland acidic rice soils under submergence with and without applied potassium (mgkg^{-1})

Incubation period (days)	Sandy clay		Loamy sand	
	K_0	$K_{45\ kg\ ha^{-1}}$	K_0	$K_{45\ kg\ ha^{-1}}$
	mgkg-1			
0	49.71 ± 0.19^d	94.75 ± 0.47^a	42.42 ± 0.31	87.42 ± 0.43^{bc}
10	49.58 ± 0.10^d	94.90 ± 0.07^a	42.29 ± 0.09	87.46 ± 0.05^b
15	49.82 ± 0.52^{cd}	94.20 ± 0.06^a	42.48 ± 0.37	87.39 ± 0.04^{bc}
20	49.70 ± 0.15^d	94.23 ± 0.52^a	42.67 ± 0.04	87.25 ± 0.05^{cd}
30	49.72 ± 0.33^d	92.68 ± 1.65^{ab}	42.53 ± 0.04	86.79 ± 0.05^e
40	50.26 ± 0.07^{bc}	89.60 ± 1.13^{bc}	42.76 ± 0.04	86.94 ± 0.02^e
50	50.34 ± 0.09^b	88.64 ± 0.06^c	42.53 ± 1.00	87.12 ± 0.06^d
60	50.98 ± 0.99^a	87.62 ± 10.08^c	42.16 ± 0.04	87.96 ± 0.10^a
ANOVA	S	S	NS	S

Means sharing similar letter(s) at different periods within a treatment do not differ significantly at $P \leq 0.05$. Data are average of seven replicates ± standard deviation (SD

HNO_3 – K

The study revealed that there was a significant increase in HNO_3 – K fraction in the clay rice soils both with and without K. The mean HNO_3 – K content was 330.66 mgkg-1 at zero level and 376.45 mgkg-1 at 45 kg ha^{-1} of added K in the sandy clay rice soils. The mean content of HNO_3 – K fraction in sandy loam soils with K addition was 204.47 $mgkg^{-1}$ whereas it was 161.47 $mgkg^{-1}$ for soils without K addition. In the sandy clay rice soils, the mean HNO_3 – K fraction increased from 351.7 to 357.3 mgkg-1 as a result of submergence. At higher level of added K significant increase in the HNO_3 – K fraction was observed on the 20^{th} day of submergence in sandy loam rice soils. However no such significant changes were observed in the HNO_3 – K fraction of clay rice soils with or without added K. The significant increase in the HNO_3 – K fraction of Pattambi soils may be due to the fixation of K in these soils. Jessymol (1993) [11] has also reported increase in HNO_3 – K associated with the period of incubation.

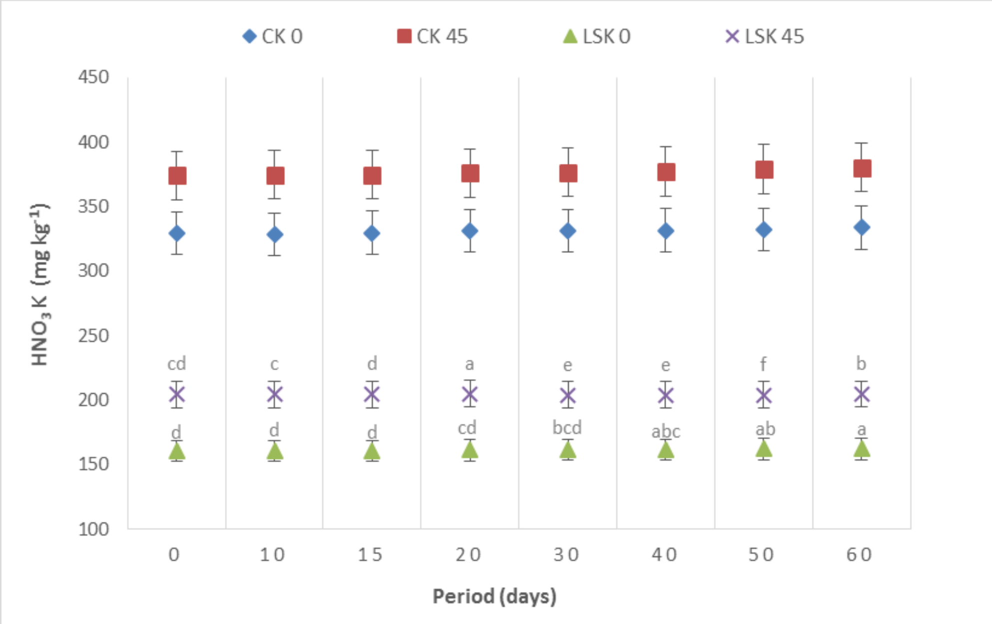

Fig 2: Temporal variation in the HNO_3 – K fraction on Pattambi and *Onattukara* soils under submergence. PS_0: Pattambi soil without K application; PS_{45}: Pattambi soil with K applied @ 45 kg ha^{-1}; OS_0: *Onattukara* soil without K application; OS_{45}: Onattukara soil with K applied @ 45 kg ha^{-1}. Error bars indicate standard error

Fixed potassium

In Pattambi soil, the increase of mean fixed K fraction from 280.8 mgkg-1 at zero level to 283.5 mgkg-1 at 45 kg ha^{-1} was significant (Table 4). The mean values of fixed K over different periods of submergence were also statistically significant which varied from 275.3 mgkg-1 to 287.9 mgkg-1. The effect of submergence was pronounced at higher levels of K where there was a significant decrease at 10 days of submergence (279.6 to 271.6 $mgkg^{-1}$) and then increased thereafter. Statistically significant increase was again observed after 30 days of submergence (284.4 mgkg-1) and then again on 50 days of submergence (290.6 mgkg-1). It increased up to 293.1 mgkg-1 on 60 days of submergence. Similar trends were also reported by Prakash and Singh (1989) [12]. The increased added K fixed might be attributed to the increase in ionic strength of potassium in soil solution which would favour a portion of K from the labile pool to occupy the inter lattice positions of clay minerals (Panda and Patra 2017) [13]. Mohammad (2004) [14] has reported that the K fixation and release behaviours of the soils are related to their mineralogical make-up. Sukumaran *et al.* (2016) [15] identified kaolinite to be the dominant clay mineral in Pattambi soils. Potassium adsorption by the wedge zones in the interlayer surfaces of weathered clay minerals is the controlling factor of K fixation in acid soils (Perkins and Tan, 1973) [16]. Having a clay content of 49% and an acidic pH of 5.4, a comparatively high level of K fixation could be expected. This clearly indicates that potassium fixation is a problem in Pattambi soils, especially when K fertilisers are applied. However in Onattukara soils, neither the K levels nor the period of incubation had any influence on K fixation.

Table 4: Effect of submergence on the fixed K fraction of Pattambi and *Onattukara* soils ($mgkg^{-1}$)

Location	Pattambi			*Onattukara*		
Levels of K ($kgha^{-1}$) Days	0	45	Mean	0	45	Mean
0	279.4	279.6	279.5	118.4	117.1	117.7
10	278.9	271.6	275.3	118.7	117.2	118.0
15	279.2	281.0	279.8	118.5	117.2	117.9
20	281.3	281.0	281.1	118.6	117.9	118.2
30	281.5	284.4	283.0	118.9	117.3	118.1
40	281.3	287.5	284.4	118.8	117.3	118.1
50	281.9	290.6	286.3	119.6	117.0	118.3
60	282.7	293.1	287.9	120.1	117.8	119.0
Mean	280.8	283.5		118.9	117.4	
CD	Treatments 2.2 Interval 4.5					

Lattice potassium
Even though a slight enhancement of lattice K fraction consequent to K addition was observed, the changes were statistically insignificant in both the soils. Due to submergence, at zero levels of K there was a slight decrease and at 45 kg level a slight increase was observed with respect to lattice K fraction irrespective of the soil types. However these changes did not bear statistical significance. This indicated that with neither the added K nor with the period of submergence, a change could be brought about in the clay mineral lattice which accommodates the lattice K fraction

Table 5: Effect of submergence on the lattice K fraction of Pattambi and *Onattukara* soils (mgkg^{-1})

Location	Pattambi			*Onattukara*		
Levels of K (kg ha^{-1}) Days	**0**	**45**	**Mean**	**0**	**45**	**Mean**
0	2921	2961	2941	2279	2276	2277
10	2922	3013	2967	2279	2275	2277
15	2921	3015	2968	2279	2276	2277
20	2919	3015	2967	2279	2275	2277
30	2919	3015	2967	2279	2276	2277
40	2919	3016	2967	2279	2276	2277
50	2918	3016	2967	2278	2276	2277
60	2916	3015	2966	2278	2275	2277
Mean	2919	3008		2279	2276	

Conclusion
Since water soluble K fraction was found to be higher in *Onattukara* soils when K was applied under submerged conditions, it can be concluded that plant availability of added potassic fertilisers would be more in these soils. The lower content of water soluble K fraction of Pattambi soils indicate that more of added K is retained in the exchange sites rather than in soil solution. Hence more than optimum application of potassic fertilisers would result only in loss of the nutrient in *Onattukara* soils. Exchangeable K on the other hand was found to be higher in Pattambi soils indicating the retention of K in the exchange sites, which would later become plant available due to the dynamic equilibrium existing between the water soluble and exchangeable K fractions. The decrease in available K coupled with the increase in HNO_3 – K and fixed K fractions with submergence in soils with added K observed in Pattambi soils is indicative of potassium fixation in this soil which is not observed in *Onattukara* soils. Significant increase of fixed K fraction observed on 30 and 50 days of submergence further confirm the intensity of K fixation in Pattambi soils. Neither submergence nor added K had an effect on the lattice K fraction which forms a part of the clay mineral lattice.

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