J. Indian Chem. Soc.,
Vol. 96, June 2019, pp. 727-735

Influence of a drying phase on K-transformation in a continuously flooded limed and the corresponding unlimed soil

Tapa Debnath, Sayan Majumder* and Dipankar Saha

Department of Agricultural Chemistry and Soil Science, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur-741 252, Nadia, West Bengal, India

E-mail: tapadebnath69@gmail.com, 1991sayan@gmail.com, d_saha11@yahoo.com

Manuscript received online 01 December 2018, revised 25 April 2018, accepted 22 May 2019

A laboratory experiment was conducted to study the effect of a drying phase on transformation of different fractions of K in a continuously flooded limed and the corresponding unlimed soil in presence and absence of N and K fertilizers. Results of the investigation revealed that irrespective of treatments, water soluble K decreased significantly with increase in the period of incubation. Liming and maintenance of a drying phase intensified the decrease of water soluble K in waterlogged acid soil. Addition of N along with K disturbs the K-equilibrium in soil as both K^+ and NH_4^+ compete for the same exchange sites. The increase in exchangeable K and concomitant decrease in non-exchangeable K in limed soil suggests a dynamic equilibrium between these two forms of K in soil. Maintenance of a drying phase in presence of N and K fertilizers released non-exchangeable K in limed soil. However, treatment of limed soil with 1 N boiling HNO_3 released more K in presence of only K than N plus K fertilizers. Changes in lattice K followed exactly an opposite trend of results with respect to non-exchangeable and 1 N boiling HNO_3 extractable K, which again suggests a dynamic equilibrium between them. Total K is not significantly influenced due to liming and maintenance of a drying phase in waterlogged acid soil over 90-day period of incubation.

Keywords: Potassium fractions, wetting and drying cycles, liming, flooded soil.

Introduction

Potassium (K) is a major essential nutrient and it is the 4th most abundant mineral element in lithosphere. K is important in stabilizing the yield and plays a vital role in determining quality of crops. This element exerts balancing effects on both nitrogen and phosphorus[1,2]. The K content of Indian soils varies from 0.50–3.00%, averaging 1.52%[3]. Continuous intensification of agriculture along with cultivation of exhaustive crops is causing heavy depletion of K in Indian soils[4]. Potassium exists in soil in four major forms; viz. water-soluble K, which is taken up directly by plants; exchangeable K, which is held by negative charges on clay particles and is available to plants; fixed K, which is trapped between layers of expanding lattice clays; and lattice K, which is an integral part of primary K bearing minerals[5].

Liming influences the K balance by increasing pH and microbial activity in soil[6]. Liming generally increases K fixation in soil[7,8]. The chemistry of NH_4^+ and K^+ in soil is quite similar because of low hydration energies and similar ionic radii of both ions. Combined application of N and K fertilizers did not show any drastic variation in non-exchangeable K in the limed soil[9].

In soils, the intensity factor (concentration of an element in the soil solution) and the capacity factor (ability of solid phases i.e. soils to replenish that element as it is depleted from solution) governs the K-availability. Moisture conditions are very much important in K availability. Soil submergence increased soluble ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions[10] which in turn displaced exchangeable K^+ in the soil solution. The increase in soluble K^+ after submergence is closely related to the ferrous ion (Fe^{2+}) content of the soil solution[11]. Continuous submergence and alternate drying and wetting increased the exchangeable potassium (K^+) which is released from non-exchangeable form[12]. Thus, maintenance of a drying phase in a continuously flooded system increases availability of K particularly to rice crops which are cultivated under submerged condition.

The effect of wetting and drying cycles along with liming on the chemistry and availability of soil potassium has not been studied sufficiently. In this backdrop, an incubation study was conducted in a continuously flooded limed and the corresponding unlimed soil subjected to a drying phase in presence and absence of N and K fertilizers.

Experimental

Instrumentation: (a) Electrical balance: Model No. PB 602-S (Monobloc inside), (b) Reciprocating rotary (180 + oscillations) shaker (Multispan), (c) Digital pH meter Model No. 802 (Systronics), (d) Electrical hot plate: Voltage – 220 V, Plate size – 250×330 mm, frequency – 50 Hz (Accumax India Pvt. Ltd.), (e) Flamephotometer: Model No. FP 102 (Chemito Tech. Pvt. Ltd.), (f) Double distillation water production Unit (Borosil, Quartz).

Materials:

(a) Reagents: Ammonium acetate (CH_3COONH_4) ≥ 97% (purity), Nitric acid (HNO_3) - min. 69% (concentration), Calcium carbonate ($CaCO_3$) - 98.3% (purity) from E. Merck (India) Ltd.

(b) Fertilizers: Urea (46.6% N), Single Super Phosphate (SSP) (16% P_2O_5), Muriate of Potash (MOP) (60% K_2O) from Tata Chemicals Ltd.

(c) Soil: Soil sample (0–15 cm depth) was collected from Regional Research Farm, BCKV (22°27′47″N, 87°0′45″E), Jhargram (P.S. + District), West Bengal during 2017. Before use; the soil was air dried, ground and passed through 2 mm sieve and stored in polythene bag.

(d) Other materials: Double-distilled water, Filter paper (Whatman No. 1)

Preparation of Limed Soil:

Liming materials ($CaCO_3$) were mixed with ½ of the total experimental soil (7.67 g of $CaCO_3$ for 3.6 kg soil according to the lime requirement as was determined by Shoemaker, Mclean and Pratt (SMP) buffer method[13]. Liming was done in separate plastic containers and liming materials were allowed to react with soil mass for 3 months with repeated moistening (with double distilled water) followed by air drying. Generally it takes 15 days to dry the moist soil at room temperature. The soil so prepared is termed as limed soil in the text. Before use, the limed soil was air dried, ground by a wooden mortar and passed through 2 mm sieve and stored in polythene bag.

The relevant physical and chemical and physico-chemical properties of both the limed and unlimed soil are presented in Table 1.

Laboratory Experiment:

The experiment was conducted in controlled laboratory condition. Both limed and unlimed soils were moistened to water logging and allowed to incubate at room temperature (30±2°C) for a period of 90 days. Loss of moisture due to evaporation was replenished by the addition of distilled water on every alternate day.

Treatments adopted in the experiment may be written as follows:

T_1 = Continuous submergence of unlimed soil throughout the experimentation period up to 90th day.

$T_2 = T_1$ + K at 60 kg K_2O ha^{-1} in the form of MOP.

$T_3 = T_1$ + N at 120 kg ha^{-1} in the form of urea + K at 60 kg K_2O ha^{-1} in the form of MOP.

T_4 = Continuous submergence of limed soil throughout the experimentation period up to 90th day.

$T_5 = T_4$ + K at 60 kg K_2O ha^{-1} in the form of MOP.

$T_6 = T_4$ + N at 120 kg ha^{-1} in the form of urea + K at 60 kg K_2O ha^{-1} in the form of MOP.

T_7 = Continuous submergence of unlimed soil upto 45th day, then a drying phase was given but again remoistened to waterlogged situation on 60th and maintained upto 90th day.

$T_8 = T_7$ + K at 60 kg K_2O ha^{-1} in the form of MOP.

$T_9 = T_7$ + N at 120 kg ha^{-1} in the form of urea + K at 60 kg K_2O ha^{-1} in the form of MOP.

T_{10} = Continuous submergence of limed soil upto 45th day, then a drying phase was given but again remoistened to waterlogged situation on 60th and maintained upto 90th day.

$T_{11} = T_{10}$ + K at 60 kg K_2O ha^{-1} in the form of MOP.

$T_{12} = T_{10}$ + N at 120 kg ha^{-1} in the form of urea + K at 60 kg K_2O ha^{-1} in the form of MOP.

Recommended fertilizer doses of N (120 kg ha^{-1}) and K_2O (60 kg ha^{-1}) for submerged rice were applied in the soils according to treatment combinations. Fertilizer doses for the incubation experiment were calculated on the basis that 1 ha furrow slice (surface soil of 0–15 cm depth) weights

Table 1. The physical, chemical and physico-chemical properties of the unlimed and limed soils used for the investigation

Soil character	Unlimed	Limed	Methodology
Physical character:			
(a) Mechanical analysis			
(i) Sand (%)	43.52		Hydrometer method (Bouyoucos, 1962)[26]
(ii) Silt (%)	24.00		
(iii) Clay (%)	32.48		
(iv) Textural class	Clay loam		ISSS system (Soil textural triangle)
(b) Water holding capacity (%)	34.35	36.35	Keen-Raczkowski box (Piper, 1942)[27]
Physico-chemical character:			
(a) pH	5.87	7.2	Glass Electrode pH meter (Black, 1965)[28]
(b) EC (dS m^{-1})	0.002383	0.005473	Electrical Conductivity Meter (Black, 1965)[28]
Chemical character:			
(a) CEC (cmol (p+) kg^{-1})	11.5	13.0	Jackson (1973)[13]
(b) Organic Carbon (%)	0.53	0.73	Walkley and Black (1934)[29]
(c) Available N (%)	0.00182	0.00098	Bremner and Keeney (1966)[30]
(d) Total N (%)	0.0896	0.0630	Bremner (1965)[31]
(e) Available P (mg kg^{-1})	0.136	0.168	Unlimed soil – Bray and Kurtz (1945)[32], Limed soil – Olsen *et al.* (1954)[33]
(f) Water soluble K (mg kg^{-1})	33.77	48.50	Jackson (1973)[20]
(g) Exchangeable K (mg kg^{-1})	103.84	117.50	
(h) Available K (mg kg^{-1})	137.61	166.00	
(i) Non-exchangeable K (mg kg^{-1})	234.89	174.00	
(j) 1 *N* HNO_3 extractable K (mg kg^{-1})	372.50	340.00	
(k) Lattice K (mg kg^{-1})	6827.50	6860.00	
(l) Total K (mg kg^{-1})	7200.00	7200.00	

approximately 2.2×10^6 kg. Application of fertilizers was done by dissolving them in distilled water. A completely randomized design (CRD) was adopted for the experiment. All the treatments were replicated thrice. Soil samples from all the sets of treatments were identically collected and analysed for different fractions of K namely, water soluble K, available K, exchangeable K (available K – water soluble K), 1 N boiling HNO_3 extractable K, non-exchangeable K (1 N boiling HNO_3 extractable K – available K), lattice K (Total K – 1 N boiling HNO_3 extractable K) and total K on 0th, 30th, 45th, 60th, 75th and 90th day of the incubation study.

Statistical analysis:

Using a computer with the help of SPSS software (SPSS 20, 2011), all the variables were statistically analyzed following methods meant for Completely Randomized Design (CRD). Their mean values were further subjected to Post-Hoc test like CD (Critical difference) to identify homogeneous means at 5% level of significance.

Results and discussion

Irrespective of treatments, water soluble K decreased significantly with increase in the period of incubation. The decrease in water soluble K is more prominent in limed over the unlimed soil except the treatment which received both N and K fertilizers and subjected to a drying phase. The decrease in water soluble K with time is due to its conversion to other forms of inorganic K. Similar trend of results were also observed earlier by Das and Saha[14]. Comparatively lower amount of water soluble K was accumulated in limed over the unlimed systems because liming owes its origin to K fixation by precipitating Al^{3+} and Fe^{3+} and freeing the blocked negatively charged sites of soils leading to the conversion of water soluble K into the exchangeable form. Mass action of Ca^{2+} (added through liming) is also responsible for the decrease of water soluble K in limed soil. Addition of K fertilizers increased water soluble K in both the limed and unlimed soils. The result is at par with earlier works of Das and Saha[15].

Table 2. Effect of a drying phase on changes in the amount (mg kg^{-1}) of water soluble K in a limed and the corresponding unlimed soil treated with and without N and K fertilizers

Treatments	Fertilizer dose	Liming	Incubation period (days)						
			0	30	45	60	75	90	Mean
Continuous submergence	N_0K_0	Unlimed	33.77	30.02	27.88	27.61	25.61	21.07	27.66
		Limed	48.50	29.60	28.81	23.58	23.37	22.72	29.43
Drying phase at 45th day		Unlimed	36.99	34.44	33.97	31.50	24.74	23.06	30.78
		Limed	57.00	31.20	30.23	28.81	27.51	19.75	32.42
Continuous submergence	N_0K_{60}	Unlimed	47.04	45.43	41.82	36.18	33.34	21.87	37.61
		Limed	58.77	39.67	36.68	33.80	33.60	32.57	39.18
Drying phase at 45th day		Unlimed	48.38	48.19	45.00	43.82	43.38	24.65	42.24
		Limed	61.24	43.20	43.01	40.08	37.89	25.75	41.86
Continuous submergence	$N_{120}K_{60}$	Unlimed	49.85	49.77	47.16	44.69	39.80	25.05	42.72
		Limed	64.78	41.20	40.50	36.43	36.16	35.47	42.42
Drying phase at 45th day		Unlimed	52.93	50.02	48.24	47.50	40.87	28.62	44.70
		Limed	50.18	43.53	43.20	39.67	37.73	30.00	40.72
	Mean		50.79	40.52	38.88	36.14	33.67	25.88	

Statistical analysis

Treatments		Incubation		Treatments×Incubation	
S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)
0.93	2.59	0.65	1.83	2.26	6.34

where, N_0K_0 = Control, N_0K_{60} = K_2O at 60 kg ha^{-1} as Muriate of Potash, $N_{120}K_{60}$ = N at 120 kg ha^{-1} as Urea and K_2O at 60 kg ha^{-1} as Muriate of Potash.

Generally, in presence of N fertilizers, K addition increased water-soluble K due to its competition with NH_4^+ ions for the exchange sites which came from the fertilizer source[16]. Perusal of the data in Table 2 further revealed that irrespective of moisture regimes, comparatively higher amount of decrease in water soluble K is recorded in limed than the unlimed soil over the 90-day period of incubation. However, the limed soil treated with both N and K fertilizers and subjected to a drying phase did not follow similar trend of results. Maintenance of a drying phase in continuously flooded soil decreased comparatively higher amount of water soluble K in soil. The drying phase caused shifting of K equilibrium and water-soluble K is converted to other forms of K[8] showing a net decrease in its amount over 90-day period of incubation. However, addition of both N and K fertilizers in a continuously flooded limed soil which received a drying phase, did not show the same intensity of decrease of water soluble K over the whole incubation period.

In general, exchangeable K decreased in limed over the unlimed soil upto 45th day of incubation (Table 3). However, a completely reverse trend of results was observed from 45th to 90th day of study. The decrease in exchangeable K at the earlier stage of incubation in limed soil is due to replacement of K by Ca^{2+} from the exchange phase[17]. However, with time, pH of the acid soil increased due to submergence. Furthermore, liming favoured microbial activities and, in turn, released K from other non-exchangeable forms (in organic combinations) to exchangeable forms[7]. Results in Table 3 further revealed that irrespective of treatments, exchangeable K in general, increased upto 30th, then decreased upto 45th and again increased on 60th day of incubation. However, 60th day onwards, exchangeable K decreased in unlimed but increased in limed systems upto 90th day of incubation. It is interesting to note that limed flooded soil which received a drying phase on 45th and rewetted on 60th day of incubation, accumulated comparatively higher order of exchangeable K particularly where N fertilizer was absent. Addition of N fertilizer along with K disturbs the K equilibrium in soil as both K^+ and NH_4^+ compete for the same exchange sites. Data in Table 3 further showed that irrespective of treatments, continuous submergence decreased exchangeable K in the unlimed soil over 90-day period of incubation which was comparatively of higher order in only K treated system.

Table 3. Effect of a drying phase on changes in the amount (mg kg^{-1}) of exchangeable K in a limed and the corresponding unlimed soil treated with and without N and K fertilizers

Treatments	Fertilizer dose	Liming	Incubation period (days)						
			0	30	45	60	75	90	Mean
Continuous submergence	N_0K_0	Unlimed	103.84	173.75	74.64	120.50	100.27	67.50	106.75
		Limed	117.50	92.50	84.77	89.14	152.94	175.65	118.75
Drying phase at 45th day		Unlimed	122.75	182.55	97.50	125.00	107.20	85.00	120.00
		Limed	75.00	100.00	67.28	135.94	181.30	267.98	137.92
Continuous submergence	N_0K_{60}	Unlimed	158.76	184.11	126.11	135.00	105.98	80.00	131.66
		Limed	87.50	103.93	99.62	151.27	228.57	244.11	152.50
Drying phase at 45th day		Unlimed	170.00	198.13	108.19	211.18	112.50	105.00	150.83
		Limed	92.50	117.50	79.97	174.77	242.62	282.14	164.92
Continuous submergence	$N_{120}K_{60}$	Unlimed	139.95	182.58	105.11	149.97	92.39	82.50	125.42
		Limed	80.00	115.00	80.66	125.00	221.84	270.00	148.75
Drying phase at 45th day		Unlimed	145.44	213.22	117.19	150.00	114.15	90.00	138.33
		Limed	119.45	112.17	97.03	160.33	249.44	273.53	168.66
Mean			117.72	147.95	94.84	144.01	159.10	168.62	

Statistical analysis

Treatments		Incubation		Treatments×Incubation	
S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)	S.Em (±)	CD(P = 0.05)
3.34	9.34	2.36	6.61	8.18	22.88

N_0K_0 = Control, N_0K_{60} = K_2O at 60 kg ha^{-1} as Muriate of Potash, $N_{120}K_{60}$ = N at 120 kg ha^{-1} as Urea and K_2O at 60 kg ha^{-1} as Muriate of Potash.

Comparatively lower amount of available K is accumulated in limed over the unlimed soil upto 60th day of incubation (Table 4). However, from 75th day onwards comparatively higher amount of available K is accumulated in limed over the unlimed soil. This trend is observed in both fertilizer treated and untreated systems. Higher amount of available K is accumulated in limed over the unlimed soil due to accumulation of higher amount of both water soluble and exchangeable K in limed over that of unlimed systems (Tables 2 and 3). The explanation furnished for accumulation of water soluble and exchangeable K is equally applicable here as well. Close examination of the data in Table 4 revealed that irrespective of treatments, available K decreased in unlimed but on the other hand, increased in limed soil over 90-day period of incubation. Maintenance of a drying phase in a continuously flooded situation increased exchangeable K which in turn increased available K in soil. The increase in available K is more prominent in K treated than both N and K treated system. This is because of the competitive nature of NH_4^+ and K^+ ions for the same exchange sites[18].

Irrespective of treatments, in general, non-exchangeable K decreased over 90-day period of incubation which is distinct in limed systems (Table 5). The increase in exchangeable K (Table 3) and the concomitant decrease in non-exchangeable K (Table 5) in limed soil over 90-day period of incubation suggest a dynamic equilibrium between these two forms of K in soil[8,15]. Comparatively higher amount of non-exchangeable K is accumulated in limed over unlimed system. Liming not only encourages microbial activities but also frees the exchange sites occupied by Fe^{3+} and Al^{3+} by precipitating them as their oxides and hence encourages fixation of exchangeable K^+ to non-exchangeable form[19]. It is interesting to note that maintenance of drying phase in a continuously flooded system released non-exchangeable K and the intensity of K release is more in limed over that of unlimed soil. Although comparatively higher amount of non-exchangeable K is accumulated in the initial stages of the investigation but maintenance of a drying phase in continuously flooded limed soil changed the orientation pattern of O-bonding and made an opening of the lattice holes leading to release of non-exchangeable K in the system[20,21]. Results in Table 5 further showed that maintenance of a drying phase in continuously flooded limed system in presence of both N and K fertilizers resulted in highest amount of release

Table 4. Effect of a drying phase on changes in the amount (mg kg^{-1}) of available K in a limed and the corresponding unlimed soil treated with and without N and K fertilizers

Treatments	Fertilizer dose	Liming	Incubation period (days)						
			0	30	45	60	75	90	Mean
Continuous submergence	N_0K_0	Unlimed	137.61	203.77	102.52	148.11	125.88	88.57	134.41
		Limed	166.00	122.10	113.58	112.72	176.31	198.37	148.18
Drying phase at 45th day		Unlimed	159.74	216.99	131.47	156.50	131.94	108.06	150.78
		Limed	132.00	131.20	97.51	164.75	208.81	287.73	170.33
Continuous submergence	N_0K_{60}	Unlimed	205.80	229.54	167.93	171.18	139.32	101.87	169.27
		Limed	146.27	143.60	136.30	185.07	262.17	276.68	191.68
Drying phase at 45th day		Unlimed	218.38	246.32	153.19	255.00	155.88	129.65	193.07
		Limed	153.74	160.70	122.98	215.25	280.51	307.89	206.85
Continuous submergence	$N_{120}K_{60}$	Unlimed	189.80	232.35	152.27	194.66	132.19	107.55	168.14
		Limed	144.78	156.20	121.16	161.43	258.00	305.47	191.17
Drying phase at 45th day		Unlimed	198.37	263.24	165.43	197.50	155.02	118.62	183.03
		Limed	169.63	155.70	140.23	200.00	287.17	303.53	209.38
	Mean		168.51	188.48	133.71	180.18	192.77	194.50	

Statistical analysis

Treatments		Incubation		Treatments×Incubation	
S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)
3.15	8.81	2.23	6.23	7.71	21.58

N_0K_0 = Control, N_0K_{60} = K_2O at 60 kg ha^{-1} as Muriate of Potash, $N_{120}K_{60}$ = N at 120 kg ha^{-1} as Urea and K_2O at 60 kg ha^{-1} as Muriate of Potash.

Table 5. Effect of a drying phase on changes in the amount (mg kg^{-1}) of non-exchangeable K in a limed and the corresponding unlimed soil treated with and without N and K fertilizers

Treatments	Fertilizer application	Liming	Incubation period (days)						
			0	30	45	60	75	90	Mean
Continuous submergence	N_0K_0	Unlimed	234.89	71.23	242.48	101.89	164.12	106.43	153.51
		Limed	174.00	217.90	276.42	142.28	63.69	99.13	162.24
Drying phase at 45th day		Unlimed	107.76	48.01	123.53	83.50	123.06	141.94	104.63
		Limed	273.00	258.80	262.49	110.25	21.19	29.77	159.25
Continuous submergence	N_0K_{60}	Unlimed	174.20	150.46	167.07	101.32	170.68	163.13	154.48
		Limed	293.73	276.40	283.70	99.93	57.83	73.32	180.82
Drying phase at 45th day		Unlimed	106.62	78.68	136.81	45.00	174.12	145.35	114.43
		Limed	371.26	359.30	292.02	104.75	39.49	42.11	201.49
Continuous submergence	$N_{120}K_{60}$	Unlimed	182.70	137.65	212.73	90.34	182.81	127.45	155.61
		Limed	335.22	343.80	178.84	111.07	27.00	114.53	185.08
Drying phase at 45th day		Unlimed	144.13	71.76	129.57	50.00	159.98	146.38	116.97
		Limed	320.37	184.30	159.77	90.00	52.83	21.47	138.12
	Mean		226.49	183.19	205.45	94.19	103.07	100.92	

Statistical analysis

Treatments		Incubation		Treatments×Incubation	
S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)
4.27	11.96	3.02	8.45	10.46	29.28

N_0K_0 = Control, N_0K_{60} = K_2O at 60 kg ha^{-1} as Muriate of Potash, $N_{120}K_{60}$ = N at 120 kg ha^{-1} as Urea and K_2O at 60 kg ha^{-1} as Muriate of Potash.

of non-exchangeable K in soil. Sharma *et al.*[22] also reported earlier that K was displaced by N-application in nitrogen deficient soil. Actually nitrogen (NH_4^+) competes with K^+ for fixation (tight fitting in the lattice holes) and replaces some amount of non-exchangeable K/Fixed K (reduced K fixation). This displaced K is positively related to non-exchangeable potassium release.

Irrespective of treatments, 1 N boiling HNO_3 extractable K decreased over 90-day period of incubation (Table 6). Boiling of soils with 1 N HNO_3 released K not only from the edge sites but also from non-exchangeable positions and hence the amount of available K is increased[9]. In general, comparatively higher amount of 1 N boiling HNO_3 extractable K is accumulated in limed systems due to increase in non-exchangeable K[23]. Critical examination of the data in Table 6 revealed that maintenance of a drying phase in continuously flooded limed soil released comparatively higher amount of 1 N boiling HNO_3 extractable K and the release is more in K treated than both N and K treated system. This is perhaps due to the presence of comparatively lesser amount of K in the exchange phase[15]. The decrease in 1 N boiling HNO_3 extractable K is of higher order in continuously flooded unlimed situations. Due to submergence, the lattices were expanded freeing non-exchangeable K and decreasing 1 N boiling HNO_3 extractable K over 90-day period of incubation.

Lattice K is the major fraction of total K. No drastic variation in lattice K is observed over the whole period of incubation study (Table 7). However, closer examination of the data revealed that changes in lattice K followed exactly an opposite trend of results compared to non-exchangeable and 1 N boiling HNO_3 extractable K throughout the whole period of incubation. The results thus clearly pointed out that there is a dynamic equilibrium among different fractions of K in soil[24]. Data in Table 7 further revealed that irrespective of treatments and stages of sampling, liming significantly increased lattice K in soils. Liming increased non-exchangeable K, a part of which was converted to the lattice K form. Maintenance of a drying phase in continuously flooded system increased lattice K over that of continuously submerged soil throughout the incubation period. Drying increased fixed K and in turn lattice K in soil.

No significant variation was observed in total K in presence of different treatments throughout the period of investigation (Table 8). The results thus clearly pointed out that

Table 6. Effect of a drying phase on changes in the amount (mg kg^{-1}) of 1 *N* boiling HNO_3 extractable K in a limed and the corresponding unlimed soil treated with and without N and K fertilizers

Treatments	Fertilizer application	Liming	Incubation period (days) 0	30	45	60	75	90	Mean
Continuous submergence	N_0K_0	Unlimed	372.50	275.00	345.00	250.00	290.00	195.00	287.92
		Limed	340.00	340.00	390.00	255.00	240.00	297.50	310.42
Drying phase at 45th day		Unlimed	267.50	265.00	255.00	240.00	255.00	250.00	255.42
		Limed	405.00	390.00	360.00	275.00	230.00	317.50	329.58
Continuous submergence	N_0K_{60}	Unlimed	380.00	380.00	335.00	272.50	310.00	265.00	323.75
		Limed	440.00	420.00	420.00	285.00	320.00	350.00	372.50
Drying phase at 45th day		Unlimed	335.00	325.00	290.00	300.00	330.00	275.00	309.17
		Limed	525.00	520.00	415.00	320.00	320.00	350.00	408.33
Continuous submergence	$N_{120}K_{60}$	Unlimed	372.50	370.00	365.00	285.00	315.00	235.00	323.75
		Limed	480.00	500.00	300.00	272.50	285.00	420.00	376.25
Drying phase at 45th day		Unlimed	342.50	335.00	295.00	247.50	315.00	265.00	300.00
		Limed	490.00	340.00	300.00	290.00	340.00	325.00	347.50
	Mean		395.83	371.67	339.17	274.38	295.83	295.42	

Statistical analysis

Treatments S.Em (±)	Treatments CD (P = 0.05)	Incubation S.Em (±)	Incubation CD (P = 0.05)	Treatments×Incubation S.Em (±)	Treatments×Incubation CD (P = 0.05)
2.74	7.69	1.94	5.42	6.71	18.78

N_0K_0 = Control, N_0K_{60} = K_2O at 60 kg ha^{-1} as Muriate of Potash, $N_{120}K_{60}$ = N at 120 kg ha^{-1} as Urea and K_2O at 60 kg ha^{-1} as Muriate of Potash.

Table 7. Effect of a drying phase on changes in the amount (mg kg^{-1}) of lattice K in a limed and the corresponding unlimed soil treated with and without N and K fertilizers

Treatments	Fertilizer application	Liming	Incubation period (days)						
			0	30	45	60	75	90	Mean
Continuous submergence	N_0K_0	Unlimed	6827.5	6945.0	6755.0	6750.0	6860.0	6835.0	6828.8
		Limed	6860.0	6910.0	6880.0	6915.0	6910.0	6822.5	6882.9
Drying phase at 45th day		Unlimed	7032.5	7335.0	7345.0	7320.0	7425.0	7350.0	7301.3
		Limed	7445.0	7370.0	7290.0	7385.0	7440.0	7182.5	7352.1
Continuous submergence	N_0K_{60}	Unlimed	6670.5	6720.0	6715.0	6747.5	6790.0	6735.0	6729.7
		Limed	6710.0	6840.0	6900.0	6925.0	6830.0	6780.0	6830.8
Drying phase at 45th day		Unlimed	7265.0	6875.0	6810.0	6700.0	6780.0	6745.0	6862.5
		Limed	7575.0	7530.0	7795.0	7795.0	7790.0	7310.0	7632.5
Continuous submergence	$N_{120}K_{60}$	Unlimed	6677.5	6750.0	6735.0	6720.0	6685.0	6765.0	6722.1
		Limed	6720.0	6715.0	6920.0	6942.5	6860.0	6700.0	6809.6
Drying phase at 45th day		Unlimed	7407.5	7365.0	7355.0	7302.5	7185.0	6835.0	7241.7
		Limed	7615.0	7775.0	7805.0	7810.0	7660.0	7575.0	7706.7
	Mean		7067.1	7094.2	7108.8	7109.4	7101.3	6969.6	

Statistical analysis

Treatments		Incubation		Treatments×Incubation	
S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)
5.50	15.39	3.89	10.88	10.87	30.41

N_0K_0 = Control, N_0K_{60} = K_2O at 60 kg ha^{-1} as Muriate of Potash, $N_{120}K_{60}$ = N at 120 kg ha^{-1} as Urea and K_2O at 60 kg ha^{-1} as Muriate of Potash.

Table 8. Effect of a drying phase on changes in the amount (mg kg^{-1}) of total K in a limed and the corresponding unlimed soil treated with and without N and K fertilizers

Treatments	Fertilizer application	Liming	Incubation period (days)						
			0	30	45	60	75	90	Mean
Continuous submergence	N_0K_0	Unlimed	7200.0	7220.0	7100.0	7000.0	7150.0	7030.0	7116.7
		Limed	7200.0	7250.0	7270.0	7170.0	7150.0	7030.0	7193.3
Drying phase at 45th day		Unlimed	7300.0	7600.0	7600.0	7560.0	7680.0	7120.0	7556.7
		Limed	7850.0	7760.0	7550.0	7660.0	7670.0	7600.0	7665.0
Continuous submergence	N_0K_{60}	Unlimed	7050.0	7100.0	7050.0	7020.0	7100.0	7500.0	7053.3
		Limed	7150.0	7260.0	7320.0	7210.0	7150.0	7000.0	7203.3
Drying phase at 45th day		Unlimed	7600.0	7200.0	7100.0	7000.0	7110.0	7130.0	7171.7
		Limed	8100.0	8050.0	8210.0	8115.0	8110.0	7020.0	8040.8
Continuous submergence	$N_{120}K_{60}$	Unlimed	7050.0	7120.0	7100.0	7005.0	7000.0	7660.0	7045.8
		Limed	7200.0	7215.0	7220.0	7215.0	7145.0	7000.0	7185.8
Drying phase at 45th day		Unlimed	7750.0	7700.0	7650.0	7550.0	7500.0	7120.0	7541.7
		Limed	8105.0	8115.0	8105.0	8100.0	8000.0	7100.0	8054.2
	Mean		7462.9	7465.8	7439.6	7383.8	7397.1	7900.0	

Statistical analysis

Treatments		Incubation		Treatments×Incubation	
S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)	S.Em (±)	CD (P = 0.05)
4.44	12.41	3.14	8.78	10.87	30.41

N_0K_0 = Control, N_0K_{60} = K_2O at 60 kg ha^{-1} as Muriate of Potash, $N_{120}K_{60}$ = N at 120 kg ha^{-1} as Urea and K_2O at 60 kg ha^{-1} as Muriate of Potash.

although dynamic changes occurred within the different fractions of K, the total K was not drastically affected over the short period of time. However, irrespective of treatments and stages of sampling, liming had a positive effect on increasing total K in soil. Maintenance of a drying phase in continuously flooded soil increased total K in the system. Drying created favourable environment for microbial activities and (decomposition of organic matter) and released some amount of K from the organic source[25]. In general, total K was more in limed soil which received a drying phase under continuously flooded situation. This trend of results is observed particularly in K-fertilizer treated systems.

Conclusion

Maintenance of a drying phase in a continuously flooded system released non-exchangeable K and the intensity of release is more in limed over that of unlimed soil. 1 N boiling HNO_3 extractable K also followed similar pattern of results. However, lattice K followed an exactly opposite trend. Both liming and drying phase did not influence total K significantly over 90 days period of investigation.

References

1. J. L. Havlin, S. L. Tisdale, W. L. Nelson and J. D. Beaton, "Soil Fertility and fertilizers: An Introduction to Nutrient Management", 8th ed., Pearson India Education Services Pvt. Ltd., Noida, 2016.
2. M. Maqsood, M. A. Shehzad, A. Wahid and A. A. Butt, *International Journal of Agriculture and Biology,* 2013, **15**, 1193.
4. G. B. Singh and A. Swarup, *Fertiliser News,* 2000, **45(2)**, 13.
5. B. N. Ghosh and A. K. Mukhopadhyay, *Journal of Potassium Research,* 1997, **13(2)**, 181.
6. U. K. Singh and S. K. Sanyal, *Journal of the Indian Society of Soil Science*, 2001, **49(1)**, 64.
7. R. Das and D. Saha, *Journal of Crop and Weed*, 2013, **9(1)**, 99.
8. S. Tripura, S. Majumder and D. Saha, *Agrochimica*, 2016, **60(4)**, 262.
8. K. Mengel and E. A. Kirkby, "Principles of Plant Nutrition", 4th ed., International Potash Institute, Bern, Switzerland, 1987.
9. S. Tripura, S. Majumder and D. Saha, *The Bioscan,* 2017, **12(2)**, 1029.
10. D. K. Das, "Introductory Soil Science. In the Chapter: Submerged Soils", Kalyani Publishers, New Delhi, India, 2015.
11. T. Debnath, S. Majumder and D. Saha, *American Journal of Applied Chemistry*, 2018, **6(6)**, 189.
12. W. Koerselman, M. B. VanKerkhoven and J. T. A. Verhoeven, *Biogeochemistry,* 1993, **20**, 63.
13. M. L. Jackson, "Soil Chemical Analysis", Prentice Hall of India Pvt. Ltd., New Delhi, 1973.
14. R. Das and D. Saha, *Journal* of *Interacademicia,* 2012, **16(3)**, 668.
15. R. Das and D. Saha, *J. Indian Chem. Soc.,* 2014, **91**, 1619.
16. T. Yan, Z. W. Xiao, Z. Hai-Tao and K. Feng, *Pedosphere*, 2008, **18**, 539.
17. C. C. Chen, F. T. Turner and J. B. Dixon, *Soil Science Society of America Journal*, 1989, **53**, 1034.
18. D. Saha, R. Mukherjee and A. K. Mukhopadhyay, *Plant and Soil*, 1982, **65**, 345.
19. L. M. Kozak and P. M. Huang, *Clays and Clay Minerals*, 1971, **19**, 95.
20. R. H. Veeh and E. O. Skogley, *Soil Science Society of America Journal*, 1986, **50**, 373.
21. A. D. Mackay and S. A. Barber, *Agronomy Journal,* 1985, **77**, 524.
22. A. Sharma, S. Arora, V. K. Jalali, V. S. Verma and B. Singh, *Communications in Soil Science and Plant Analysis*, 2012, **43(15)**, 2050.
23. G. K. Sarkar, *Journal* of *Interacademicia*, 2009, **13(4)**, 418.
24. B. Sood, S. K. Subehia and S. P. Sharma, *Journal of the Indian Society of Soil Science*, 2008, **56(1)**, 54.
25. F. Habib, S. Javid, I. Saleem, S. Ehsan and Z. A. Ahmed, *Soil and Environment*, 2014, **33(2)**, 110.
26. G. Bouyoucos, *Agronomy Journal*, 1962, **54**, 464.
27. C. S. Piper, in: 'Soil and Plant Analysis', University of South Australia, 1942.
28. C. A. Black, "Method of Soil Analysis. Part 2. Chemical and Microbiological Properties", American Society of Agronomy, Inc, Publisher, Madison, Wisconsin, USA, 1965.
29. A. Walkley and I. A. Black, *Soil Science,* 1954, **37**, 29.
30. J. M. Bremner and D. R. Keeney, *Soil Science Society of America Proceedings*, 1966, **30,** 577.
31. J. M. Bremner, in: 'Inorganic Forms of Nitrogen. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties', 1965, pp. 1179-1237.
32. R. H. Bray and L. T. Kurtz, *Soil Science*, 1945, **59**, 39.
33. S. R. Olsen, C. V. Cole, F. S. Watnabe and L. A. Dean, US Department Agriculture Circular, Washington, DC, 1954, **939**, 18-19.