Original Research Article

Releasing Patterns of Potassium and its Relationship with Different Forms of Potassium in Acid Alfisols Soils of Ranchi, Jharkhand

ABSTRACT

A study was conducted during 2017-2018 at the Experimental Farm of Birsa Agricultural University, Kanke, Ranchi, Jharkhand to assess the releasing patterns of potassium and its relationship with different forms of potassium in surface (0-15 cm) and sub-surface (16-30 cm) soils of acid alfisols from the selected 9 treatments under long-term nutrient management practices in maize-wheat cropping system. The releasing power of soil potassium is an index of the availability of the nutrient to the crops over a longer duration and in general, it indicates the sum of water-soluble K, exchangeable K, and a fraction of non-exchangeable K which is not immediately available to the growing plants, but will be slowly available over a longer period (Nash, 1971). Repeated extraction with boiling 1N HNO_3 has been suggested as one of the methods to assess the potassium-releasing capacity of soils. In this context, cumulative K, constant rate K, and step K as a part of non-exchangeable potassium proposed by Haylock (1956) measure the potassium-releasing capacity of soils more effectively under intensive crop cultivation. The amount of K release in successive extraction with boiling 1N HNO_3 decreased consistently and reached a plateau at the 8th and 9th extraction steps in both depths of soils. Cumulative K is highest in INM (T_6) while constant rate K and step K are highest in Lime, FYM, P_2O_5, and K_2O treated plots (T_8). The lowest contribution of potassium release patterns is generally observed in the control plot (T_1). Also, the K release was found to be maximum in surface soils than in sub-surface soils concerning various selected treatments. Cumulative K, Constant- rate K, and Step K had highly significant and positive correlations with different forms of potassium (Water soluble K, Exchangeable K, Non-Exchangeable K, Total K, and Lattice K) in both depths. The potassium-releasing patterns evaluated through cumulative K, constant rate K, and step K could be meaningful for making fertilizer recommendation programmes, especially in intensively cultivated areas. Hence, the importance of study in terms of the possible contribution to plant available pool of soil K through potassium release patterns in two depths of given soil has been pointed out.

Keywords: K release, cumulative K, total step K, constant rate K.

1. INTRODUCTION

The complex problem of soil fertility management especially with reference to potassium fertilization can only be studied by long-term field trials as it synchronizes time for crop and cropping systems, manures, and fertilizers to have a measurable effect on soil fertility. A similar research work on long-term soil fertility management in maize-wheat cropping system was initiated in 1956 under Permanent Manurial Trial at the Experimental Farm, of Birsa Agricultural University, Ranchi, Jharkhand which aimed at concomitant improvement in soil fertility and productivity. The study area represents the assessment of releasing patterns of potassium and its relationship with different forms of potassium in the representative soil sample. Since potassium itself is a quality cation that holds paramount importance in plant growth and development which exists in soils in various forms and combinations and their releasing pattern to plants differs widely (Divya *et a*l., 2017). The releasing power of soil potassium is an index of the availability of the nutrient to the crops over a longer duration and in general, it indicates the sum of water-soluble K, exchangeable K, and a fraction of non-exchangeable K which is not immediately available to the growing plants, but will be slowly available over a long period (Nash, 1971). Thus the K releasing power refers to the total K available K in soil equivalent to the actual amount absorbed by plants. Several methods have been employed from time to time in devising better methods of potassium releasing *vis-à-vis* potassium supplying power of soils and in comprehending the K release characteristics under varying soil, environmental, and cropping conditions. Repeated extraction with boiling 1N HNO_3 has been suggested as one of the methods to assess the potassium-supplying power of soils. In this context, step K and constant rate K as proposed by Haylock (1956) measure the K-releasing capacity of soils more effectively under intensive crop cultivation (Haylock, 1956 and Divya et al., 2017). Step K is the relatively soluble fraction of soil K and actually estimates the plant utilizable non-exchangeable K. The constant rate K (CR-K) measures the difficult fraction of soil K and gives an idea about the rate of K release from mineral lattice under long-term cropping conditions. The feasibility of these parameters to measure the K-releasing capacity of different soils under intensive crop cultivation was evaluated by several workers (Patra *et al*., 2008). At this juncture, an in depth study concerning potassium behaviour under a long-term nutrient management-based cropping system was contemplated for a better understanding of the behaviour of this element and also to elucidate information on potassium supplying power in the surface (0-15 cm) and sub-surface (16-30 cm) soils of maize-wheat cropping system under long term nutrient management practices for formulating more precise potassic fertilizer recommendations.

2. MATERIALS AND METHODS

2.1 Experimental Details

The field study was started in 2017-2018 as a part of an ongoing Permanent Manurial Trial (PMT) initiated in 1956 on the maize-wheat cropping system on acidic red loamy soil at the Experimental Farm of Birsa Agricultural University, Kanke, Ranchi, Jharkhand. The experiment was laid out in Randomized Block Design with 3 replications and 14 treatments in each replication having a plot size of 10 m^2. Out of 14 treatments, 9 different treatments were considered for the present study with 3 replications. The treatment details are presented in Table 1. The recommended dose of N: P_2O_5: K_2O has been 110, 90, and 70 kg ha^{-1}, respectively, since 1976. Lime is applied as per lime requirement in treatments once in four years. FYM is applied based on N content as per the treatments@ 22 t ha^{-1} 15 days before the sowing of each crop. Phosphorous and potassium are applied as basal and nitrogen is applied in splits for both the crops. The sources of N, P, and K were urea, single superphosphate (SSP), and muriate of potash (MOP), respectively. The varieties Suwan composite and HD 2967 for maize and wheat were used as a test crop respectively.

Table 1: Details of the various treatments of the long-term field experiment

Treatment No.	Treatment description	Particulars
T_1	Control	No fertilizer, manure, or lime
T_2	100 % N	110 kg N ha^{-1} as urea
T_3	FYM	FYM was applied @ 22 t ha^{-1}, 15 days before sowing of Maize-wheat crop
T_4	100 % NP	110 kg N ha^{-1} as Urea + 90 kg P_2O_5 kg ha^{-1} as Single Super Phosphate (SSP)
T_5	100 % NPK	110 kg N ha^{-1} as urea + 90 Kg P_2O_5 Kg ha^{-1} as SSP+70 Kg K_2O as MOP
T_6	½ (N+FYM) + $P_{(A-X/2)}$ + $K_{(B-Y/2)}$ (INM)	50% N substituted through FYM and NPK (55.0 kg N ha^{-1} as urea + 55.6 kg P_2O_5 kg ha^{-1} as SSP+42.9 kg K2O as MOP
T_7	100 % NPK + Lime	Lime as per LR (once in four years) + NPK (110 kg N ha^{-1} as urea + 90 kg P_2O_5 kg ha^{-1} as SSP+70 Kg K_2O as MOP)
T_8	Lime+ FYM+$P_{(A-X)}$ +$K_{(B-Y)}$	Lime as per LR (once in four years) + FYM (22 t ha^{-1}) + 55.6 kg P_2O_5 kg ha^{-1} as SSP+42.9 kg K_2O as MOP
T_9	Lime + N	Lime as per LR (once in four years) + N @110 kg N ha^{-1} as Urea

2.2 Collection and Analysis of Soils

A total of 54 composite soil samples were collected at two different depths *viz.* 0-15 cm (surface depth) and 16-30 cm (sub-surface depth) after the harvest of the crop from each plot of the experimental field of the nine selected treatments replication wise. The soil samples collected were air-dried in the shade and gently ground using a wooden pestle and mortar to pass through a 2 mm sieve. The sieved samples were preserved in stoppered plastic containers for further analysis. Processed and well-dried soil samples were used to analyze the various forms of potassium by using the standard soil: extractant ratio with standard and specific methods for each.

2.3 Potassium Release Pattern of Soils

The potassium-releasing parameters such as step K, constant rate K, and cumulative release K were derived as per the procedure of Haylock (1956) using I N boiling HNO_3 as an extractant. One gram of soil was taken in a centrifuge tube and treated with 10 ml of 1N HNO_3. The contents were heated for 10 min on a hot water bath and centrifuged for 10 minutes at 2000 rpm. The K in the supernatant liquid was determined with the help of a flame photometer. To the same soil, another 10 ml of 1N HNO_3 was added and the same procedure of boiling the sample, centrifugation, and K estimation was followed. The above process was repeated till the amount of K released in successive extractions was constant.

2.3.1 Step K

The amount of total step K was calculated as, step K = {(The amount of K extracted (cumulative) by boiling 1N HNO_3 till constancy in K release is reached) – (The amount of CR-K x Total number of extractions)}.

2.3.2 Constant Rate K

After several repeated extractions of soil by boiling 1N HNO_3, the potassium extracted reached a constant value.

2.3.3 Cumulative K Release

The cumulative K released was calculated by adding all the values of K extracted by successive extractions.

3. Statistical Analysis

The data sets were processed for analysis of variance as applicable to randomized block design using the least significant difference as described in Gomez and Gomez (1984). Treatment means were compared at 1% or 5% level of significance. Correlation studies were carried out among the parameters of soil using Microsoft Excel.

4. Results and Discussions

The activity of K^+ ions in the soil solution is a factor for determining the K release from the soil. The potassium release parameters were studied to understand potassium release patterns in maize–wheat cropping systems due to long-term soil fertility or nutrient management practices. The quantity of K released from this form of K usually had a direct relation to the quantity of K applied to the soil and the quantity of K taken by the crops. There is a need to include part of non-exchangeable K in the available portion while assessing K availability to the crops. Subba Rao (1984) suggested that there is a need for the use of methods of analysis that would extract K from the reserve pool in the soil if the long-term K-supplying power of soil is to be assessed. The method suggested by Haylock (1956) simulates the potassium depletion pattern under an intensive cropping system. The amounts of soil K released in ninth extractions scheduled with boiling 1N HNO_3 for the representative soils from the selected treatments belonging to soil orders acid alfisols have been presented in Table 2 & Table 3. The results showed that with successive extraction the amount of K release decreased step wisely in all the soils of different treatments and reached a plateau at the 8th to 9th extractions.

4.1 Step K

The step K represents a more soluble K fraction of boiling 1N HNO_3 the part of non-exchangeable potassium that is available to crop in due course under intensive crop growing conditions. The value of step K ranged from 688.4 to 1197 kg ha^{-1} at surface soils and 683.5 to 1188.2 kg ha^{-1} at sub-surface soils was affected by nutrient management practices in selected 9 treatments under long-term trial. Higher value of step K indicated greater K supplying power of soils which was observed in T_8. Similar result was also found by Das *et al.,* (1997) and Prasad (2003). Lower values of K in untreated soil T_1 (i.e. in the control plot) were the result of K exhaustion from soil and the release of a comparatively lesser amount of potassium from a secondary mineral (Prasad, 2003).

4.2 Constant Rate K (CR-K)

Constant rate K is the amount of potassium in soil having limited solubility during the later extraction designed as constant rate K. Constant rate K provides an estimate of the availability of K from a mineral lattice source. The constant rate K estimated by successive extractions reached to plateau at the 8th and 9th extractions step and the CR-K value varied from 22.3 to 25 kg/ha in surface soils and 19.2 to 24.1 kg/ha in sub-surface soils. By this, it could be understood that irrespective of the various selected 9 treatment combinations studied, the reserve pool of available K was depleted very slowly in soils. This behaviour seems to indicate that the reserve pool of available/non-exchangeable K may contribute considerably to the K nutrition of the crops over a long period. Incidentally, in the case of Treatment T_8 with higher amounts of cumulative K release, the CR-K encountered was also high rather late than in the case of those which had relatively lower amounts of CR-K. Hence, there is every reason to believe that the treatment combinations having both organic and inorganic K supply may meet the K needs of crops for a longer period as compared to those that received no K fertilizer or only inorganic K received plots. This suggests that soil fertility management through INM in the intensive cropping system may meet the long-term needs of the crop as suggested by Haylock (1956) and M. Divya *et a*l (2017).

4.3 Cumulative K Release (CPR)

The CPR values estimated by successive extractions with boiling 1N HNO_3 varied between 1453.8 to 2295.8 kg ha-1 in surface soils and 1395.9 to 2241.5 kg ha^{-1} in sub-surface soils of the various selected 9 treatment combinations as influenced maize-wheat cropping system under long-term trial. Irrespective of the treatments studied much of the total cumulative K was released by the end of the second or third extraction, and the K release became very slow from then onwards. The amount of total or the different forms of K, released a substantial proportion of their cumulative K which probably included the major portion of the so-called non-exchangeable K- relatively easily upon depletion of the exchangeable K from the exchange complex. The reason for the removal of relatively larger quantities of cumulative K from T_8 may be attributed to the higher buffering capacity or K supply power of the plot and also the presence of relatively larger quantities in the clay fractions. This treatment also had relatively higher amounts of nonexchangeable K and more of exchange sites and finer clay content. The results are in conformity with the findings of Bansal and Sekhon (1976). On the other hand, relatively lower amounts of cumulative K were noticed in the control plot (T_1). This could be attributed to lower buffing capacity or K supply power due to inadequate K management practices followed over the years. A similar observation was made by Agarwal (1965) and Boruah *et al* (1990), and M.Divya *et al* (2017) who reported lower cumulative K release from soils with poor management practices.

5 Relationship Between Different Forms of K and Step K in Surface Soil

The correlation coefficient (r) values worked out among the various soil parameters at two different depths of soil (0-15cm and 16-30 cm) in the Maize Wheat cropping system. From Table 4, it was evident that the Available K was found to be highly significant and positively correlated with Water soluble K and Exchangeable K (r=0.997**& 0.998**, respectively). It was significant and positively correlated with $1NHNO_3$ K, Step K, Constant K, and Cumulative K release (r=0.789*,0.790*,0.722*, 0.783* respectively). Water soluble K was highly significant and positively correlated with available K, and exchangeable K (r=0.997**& 0.997**, respectively). It was significant and positively correlated with $1NHNO_3$ K, Step K, Constant K, and Cumulative K release (r=0.778*,0.779*,0.711*,0.772*, respectively). Exchangeable potassium was highly significant with Available K, and Water soluble K (r=0.998**, 0.997**, respectively). Whereas it was significantly and positively correlated with $1NHNO_3$ K, Step K, Constant K, and Cumulative K release (r=0.791*,0.791*,0.723*, 0.784*, respectively). Non-exchangeable K was observed (Sharma (2001) and Keskar *et al.,* (2001) to be highly significant and positively correlated with 1 $NHNO_3$ K, Total K, Step K, Constant rate K, Cumulative K release (r=0.973**,0.866**,0.973**,0.979**,0.974**, respectively). Kinetic parameters of the first-order equation were related to non-exchangeable forms of K, i.e. 3 N H_2SO_4 K and 1 N boiling HNO_3 K (Table 4). A highly significant correlation between cumulative K and non-exchangeable K forms shows that a fraction of the total non-exchangeable K in soil was released into these dilute extractants. Release rate constants showed a significant relationship with the non-exchangeable form of K in the soil. However, the r values were higher for 3 N H_2SO_4 K than for boiling 1 N HNO_3 K. Extraction of soil K in boiling nitric acid is considered to be a drastic dissolution of clay structure (Datta and Sastry, 1993), which results in the extraction of greater amounts of K and lower r values with K released in dilute extractants. Similarly, intercept values showed a significant correlation with non-exchangeable K, as the extrapolated intercept is assumed to be proportional to the initial K content at time Hence, the higher the intercept value, the greater the initial K content. Srinivasa Rao *et al*., (1999). Lattice K was found to be highly significantly and positively correlated with the Total K (r=0.939**).$1NHNO_3$ was observed to be highly significant and positively correlated with the Non-exchangeable K, Total K, Step K Constant rate K, Cumulative K (r=0.973**, 0.998**, 0.985**, 0.999**, respectively). It was found to be positively and significantly correlated with the Available K, Water soluble K, Exchangeable K, Total K, Step K, and Cumulative K (r=0.789*, 0.778*& 0.791*,0.777**, respectively). Total K was observed to be highly significant and positively correlated with the Non-exchangeable K, Lattice K, Constant rate K, and Cumulative K (r=0.866**,0.939**,0.857**, respectively). It was found to be positively and significantly correlated with the $1NHNO_3$ K, Step K, and Cumulative K (r=0.777*, 0.777*&0.790*, respectively). Step K was observed to be highly significant and positively correlated with the Non-exchangeable K, 1NHNO3, Total K, Constant rate K, Cumulative K (r=0.973**, 0.998**, 0.777**, 0.985**, 0.999**, respectively). It was found to be positively and significantly correlated with the Available K, Water soluble K, and Exchangeable K (r=0.790*,0.779*& 0.791*, respectively). The Constant rate K was observed to be highly significant and positively correlated with the Non-exchangeable K, $1NHNO_3$ K, Total K, Step K, Cumulative K (r=0.979**, 0.985**, 0.857**, 0.985**, 0.999**, respectively). It was found to be positively and significantly correlated with the Available K, Water soluble K, and Exchangeable K (r=0.722*, 0.711*& 0.732*, respectively). These results are supported by the findings of Kumar (1990) working with red loam soils of Ranchi also observed a significant positive relationship of soil potassium supply with step K and constant rate K. A Similar result was also found by Kumar (2000) in red soil of Ranchi. Constant rate K and cumulative K release showed a highly significant positive correlation with different forms of K. Similar observations were earlier recorded by Roy *et al.,* (1993) and Surekha *et al.,* (1996). Cumulative K release (kg ha^{-1}) was found to be highly significant and positively correlated with the non-exchangeable K, $1NHNO_3$ K, Total K, Step K, Constant rate K (r=0.974**, 0.999**, 0.999**, 0.988**, respectively). It was significantly and positively correlated with available K, water-soluble K, exchangeable K, and total K (r=0.783*, 0.772*, 0.784*, 0.790*, respectively).

6 Relationship Between Different Forms of K and Step K in Sub-Surface Soil

The correlation coefficient (r) values worked out among the various soil parameters at the depth of soil (16-30 cm) in the Maize Wheat cropping system. From Table 5, it was evident that the Available K was found to be highly significant and positively correlated with Water soluble K and Exchangeable K (r=0.999**& 0.998**, respectively). It was significant and positively correlated with 1NHNO$_3$ K, Step K, Constant K, Cumulative K release (r=0.790*,0.791*,0.688*, 0.783*, respectively). Water soluble K was highly significant and positively correlated with available K, exchangeable K, Lattice K,1NHNO$_3$ –K, Total K, Step K, Constant rate-K, Cumulative K (r=0.999**, 0.999**, 0.999**, 0.999**, 0.999**, 0.999**,0.999**,0.999**& 0.999**, respectively). It was significant and positively correlated with 1NHNO$_3$ K, Step K, Constant K, and Cumulative K release (r=0.778*,0.779*,0.711*,0.772*, respectively). Exchangeable potassium was highly significant with Available K, and Water soluble K (r=0.998**, 0.999**, respectively). Whereas it was significantly and positively correlated with 1NHNO$_3$ K, Step K, Constant K, and Cumulative K release (r=0.790*, 0.791*, 0.687*, 0.782*, respectively). Non-exchangeable K was observed (Sharma (2001) and Keskar *et al.,*(2001) to be highly significant and positively correlated with 1 NHNO$_3$, Total K, Step K, Constant rate K, Cumulative K release (r=0.973**, 0.866**, 0.973**, 0.972**, 0.974**, respectively).Kinetic parameters of the first-order equation were related to non-exchangeable forms of K, i.e. 3 N H_2S_O4 K and 1 N boiling HNO$_3$ K (Table 5). A highly significant correlation between cumulative K and non-exchangeable K forms shows that a fraction of the total non-exchangeable K in soil was released into these dilute extractants. Release rate constants showed a significant relationship with the non-exchangeable form of K in the soil. However, the r values were higher for 3 N H_2SO_4 K than for boiling 1 N HNO$_3$ K. Extraction of soil K in boiling nitric acid is considered to be a drastic dissolution of clay structure (Datta and Sastry,1993), Lattice K was found to be highly significantly and positively correlated with the Total K (r=0.938**) which results in extraction of greater amounts of K and lower r values with K released in dilute extractants. Similarly, intercept values showed a significant correlation with non-exchangeable K, as the extrapolated intercept is assumed to be proportional to initial K content at time 0. Hence, the higher the intercept value, the greater the initial K content. Srinivasa Rao *et al*., (1999). 1NHNO$_3$ was observed to be highly significant and positively correlated with the Non-exchangeable K, Step K Constant Rate K, and Cumulative K (r=0.973 **, 0.998**, 0.968**, 0.999**, respectively). It was found to be positively and significantly correlated with the Available K, Water soluble K, Exchangeable K, and Total K (r=0.790*, 0.796*& 0.790*,0.775**, respectively). Total K was observed to be highly significant and positively correlated with the Non-exchangeable K, Lattice K, Constant rate K, and Cumulative K (r=0.866**,0.938**,0.855**, respectively). It was found to be positively and significantly correlated with the 1NHNO$_3$K, Step K, and Cumulative K (r=0.775*, 0.774*& 0.797*, respectively). Step K was observed to be highly significant and positively correlated with the non-exchangeable K, 1NHNO3, Constant rate K, and Cumulative K (r=0.973**, 0.998**, 0.967**& 0.999**, respectively). It was found to be positively and significantly correlated with the Available K, Water soluble K, Exchangeable K, and Total K (r=0.791*,0.779*& 0.791* &0.774*, respectively). The Constant rate K was observed to be highly significant and positively correlated with the Non-exchangeable K, 1NHNO$_3$ K, Total K, Step K, Cumulative K (r=0.972**, 0.968**, 0.855**, 0.967**,0.974**, respectively). It was found to be positively and significantly correlated with the Available K, Water soluble K, and Exchangeable K (r=0.688*, 0.693*& 0.687*, respectively). These results are supported by the findings of Kumar (1990) working with red loam soils of Ranchi also observed a significant positive relationship of soil potassium supply with step K and constant rate K. A Similar result was also found by Kumar (2000) in red soil of Ranchi. Constant rate K and cumulative K release showed a highly significant positive correlation with different forms of K. Similar observations were earlier recorded by Roy *et al.,*(1993) and Surekha *et al.,* (1996,2006,2009).Cumulative K release(kg ha^{-1}) was found to be highly significant and positively correlated with the non-exchangeable K, 1NHNO$_3$ K, Total K, Step K, Constant rate K (r=0.974**, 0.999**, 0.999**, 0.974**, respectively).It was significantly and positively correlated with Available K, Water soluble K, Exchangeable K, and Total K (r=0.783*, 0.788*, 0.782*, 0.797*, respectively).

Table 2: Effect of nutrient management practices on step K of surface soil after 62 crop cycles under maize-wheat cropping system

Treatments		Extraction number (0-15 cm)									Step K (kgha^{-1})	Constant rate K (kgha^{-1})	Cumulative K release (kgha^{-1})
		1st step	2nd	3rd	4th	5th	6th	7th	8th	9th			
T$_1$	Control	710.7	360.2	152.1	75.5	48.1	35.3	27.1	22.3	22.3	688.4	22.3	1453.6
T$_2$	100 % N	794.1	383.7	168.4	79.3	51.2	37.1	26.6	22.7	22.7	771.4	22.7	1585.8
T$_3$	FYM	870.73	427.6	177.9	85.7	59.1	38.6	27.5	23.5	23.5	847.23	23.5	1734.13
T$_4$	100 % NP	765.9	372.5	159.9	77.1	49.9	37	26	22.5	22.6	743.3	22.6	1533.4
T$_5$	100 % NPK	945	441.1	183.3	91.1	59.9	37	27.6	23.8	23.8	921.2	23.8	1832.6
T$_6$	½ (N+FYM) + P (A-X/2) + K (B-Y/2) (INM)	1050.7	521.7	197.6	92.3	61.1	38.7	27.9	24.3	24.3	1026.4	24.3	2038.6
T$_7$	100 % NPK + Lime	954.5	446.2	187.7	91.7	59.9	37.9	27.5	23.9	23.9	930.6	23.9	1853.2
T$_8$	Lime +FYM+P(A-X)+K(B-Y)	1222	589.7	213.2	93.5	60.6	38.9	27.9	25	25	1197	25	2295.8
T$_9$	Lime + N	762.5	369.3	158.1	77	49.1	37	25.8	22.5	22.5	740	22.5	1523.8

Table 3: Effect of nutrient management practices on step K of sub-surface soil after 62 crop cycles under maize-wheat cropping system

Treatments		Extraction number (16-30 cm)									Step K (kg ha^{1})	Constant rate K (kg ha^{-1})	Cumulative K release (kg ha^{-1})
		1st step	2nd	3rd	4th	5th	6th	7th	8th	9th			
T_1	Control	702.7	349	142.3	69.7	39.8	32.7	21.3	19.2	19.2	683.5	19.2	1395.9
T_2	100 % N	785	369.7	154.4	72.9	48.2	35.3	21.7	20.1	20.1	764.9	20.1	1527.4
T_3	FYM	862.47	411.3	159.8	77.3	51.3	37.4	22.3	20.4	20.4	842.07	20.4	1662.67
T_4	100 % NP	756.5	353.9	148.1	70.3	44.5	34.1	21.5	19.7	19.7	736.8	19.7	1468.3
T_5	100 % NPK	945.8	439.9	181	90.2	57.7	34.9	27.1	22.6	22.6	923.2	22.6	1821.8
T_6	½ (N+FYM) + P (A-X/2) + K (B-Y/2) (INM)	1041	509.3	188.3	89.9	57.9	35.3	24.5	23.1	23.1	1017.9	23.1	1992.4
T_7	100 % NPK + Lime	945.9	437.7	169.5	88.8	53.7	33.8	23.9	22.4	22.4	923.5	22.4	1798.1
T_8	Lime +FYM+P(A-X)+K(B-Y)	1212.3	571.1	201.1	90.9	58.8	34.2	24.9	24.1	24.1	1188.2	24.1	2241.5
T_9	Lime + N	754.6	351.2	147.9	71.7	42.7	33.3	22.3	19.7	19.7	734.9	19.7	1463.1

Table 4: Correlation coefficient of forms of K and Step K in surface soil.

	Available K (kg ha^{-1})	Water soluble K (kg ha^{-1})	Exchangeable K (kg ha^{-1})	Non - exch. K (kg ha^{-1})	Lattice K (kg h-^{1})	1NHNO$_3$ K (kg ha^{-1})	Total K (kg ha-^{1})	Step K (kg h-^{1})	Constant rate-K (kg ha^{-1})	Cumulative K release (kg ha^{-1})
Available K(kg ha^{-1})	1									
Water soluble K(kg ha^{-1})	0.997**	1								
Exch. K(kg ha^{-1})	0.998**	0.997**	1							
Non-exch. K(kg ha^{-1})	0.627	0.614	0.628	1						
Lattice K(kg ha^{-1})	0.006	0.016	0.005	0.649	1					
1NHNO$_3$ K(kg ha^{-1})	0.789*	0.778*	0.791*	0.973**	0.513	1				
Total K(kg ha^{-1})	0.321	0.324	0.321	0.866**	0.939**	0.777*	1			
Step K (kg ha^{-1})	0.790*	0.779*	0.791*	0.973**	0.512	0.998**	0.777*	1		
Constant rate-K (kg ha^{-1})	0.722*	0.711*	0.723*	0.979**	0.629	0.985**	0.857**	0.985**	1	
Cumulative K release (kg ha^{-1})	0.783*	0.772*	0.784*	0.974**	0.531	0.999**	0.790*	0.999**	0.988**	1

****Significant at 1%level of significance**

***Significant at 5% level of significance**

Table 5: Correlation coefficient of forms of K and Step K in sub-surface soil.

	Available K (kg ha^{-1})	Water soluble K (kg ha^{-1})	Exch. K (kg ha^{-1})	Non-exch. K (kg ha^{-1})	Lattice K (kg ha^{-1})	1NHNO$_3$ K (kg ha^{-1})	Total K (kg ha^{-1})	Step K (kg ha^{-1})	Constant rate-K (kg ha^{-1})	Cumulative K release (kg ha^{-1})
Available K (kg ha^{-1})	1									
Water soluble K (kg ha^{-1})	0.999**	1								
Exch. K (kg ha^{-1})	0.998**	0.999**	1							
Non-exch. K (kg ha^{-1})	0.629	0.636	0.628	1						
Lattice K (kg ha^{-1})	-0.002	0.001	-0.002	0.647	1					
1NHNO$_3$ K (kg ha^{-1})	0.790*	0.796*	0.790*	0.973**	0.509	1				
Total K (kg ha^{-1})	0.316	0.321	0.316	0.866**	0.938**	0.775*	1			
Step K (kg ha^{-1})	0.791*	0.797*	0.791*	0.973**	0.508	0.998**	0.774*	1		
Constant rate-K (kg ha^{-1})	0.688*	0.693*	0.687*	0.972**	0.635	0.968**	0.855**	0.967**	1	
Cumulative K release (kg ha^{-1})	0.783*	0.788*	0.782*	0.974**	0.539	0.999**	0.797*	0.999**	0.974**	1

****Significant at 1%level of significance**

***Significant at 5%levelofsignificance**

CONCLUSIONS

Based on the experimentation, the major portion of cumulative K from almost all the treatment combinations was released by the fourth extraction with the reagent *viz*., 1N HNO_3. The total amount of cumulative K release varied from 1453.8 to 2295.8 kg ha^{-1} in surface soils and1395.9 to 2241.5 kg ha^{-1} in sub-surface soils while step K ranged from 688.4 to 1197 kg ha^{-1} at surface soils and 683.5 to 1188.2 kg ha^{-1} at sub-surface soils due to the imposition of different treatments. Step K of soils was found to have a similar pattern as observed in the case of cumulative release K. The treatments involving the incorporation of Lime, FYM, P_2O_5, and K_2O released a relatively higher amount of K than the control and other treated plots. In most of the treatments, a constant rate K was encountered by the 8th or 9th extraction indicating K releasing power of soils for a long period. The Constant rate-K values were higher in treatment T_8 followed by T_6 and lower for T_1 (control) followed by T_9 and T_2 (treatment having less K nourished and lower organic matter content). The K release was found to be higher in surface soils than in sub-surface soils concerning various selected treatments. Cumulative K, Constant- rate K, and Step K had highly significant and positive correlations with different forms of potassium (Water soluble K, Exchangeable K, Non-Exchangeable K, Total K, and Lattice K) in both depths. Even though many long-term fertilizer experiments are going in on different cropping systems in various parts of the country seem to be possessing good K supplying and K releasing power. Especially with reference to maize – wheat cropping system under acid alfisols neither organic sources alone nor mineral fertilizers can achieve sustainability for maintaining the K supplying power of these soils, regular and judicious but conjoint application of K through K fertilizers, organic manures, and lime is a necessity because of poor soil management.

Thus, from the above results and conclusion of an experiment, the importance of long-term fertilizer experiments was felt in aspects of sustainable maintenance of soil fertility per unit area per unit time per unit input without detrimental effects on the soil environment and soil health in an intensive cropping system. There is a necessity for continuous monitoring of changes in nutrient dynamics. So, long-term fertilizer experiment provides a resource of soil and plant material to further scientific research into soil and plant processes that control soil fertility, and plant productivity.

ACKNOWLEDGEMENTS

The authors express their sincere gratitude and thanks to Dr. Dhirendra Kumar Shahi, Head of the Department of Soil Science and Dean of Birsa Agricultural University, Kanke, Ranchi, Dr. Prabakar Mahapatra, Junior Scientist-cum-Assistant Professor, and all the supportive members of the department for their valuable and constructive suggestions during the planning and development of the research work and its implementation. The necessary facilities provided by the Department of Soil Science and collaboration with other departments during the itinerary of research work are highly acknowledged.

COMPETING INTERESTS

The authors have declared that no competing interests exist

REFERENCES

Agarwal RR (1965) *Soil fertility in India.* Asia Publication House, Bombay.

Bansal BD, Sekhon GS (1976) Influence of nature and amount of clay on potassium availability of some alluvial soils. *Bulletin- Indian Soc. Soil Sci.* **10**, 78-85.

Bansal SK, Umar S (1998). Nutrient indexing of crop plants grown on twenty six benchmark soil series of India. *Journal of Potassium Research,***15**: 7-18.

Boruah HC, Bora DK, Nath AK (1990) Potassium release characteristics of three major soil orders of Assam. *J. Potash. Res*. **6**(4), 139-144.

Das PK, Acharya N, Das HK, Sahu GC (1997). Potassium release characteristics of some soils in the watershed areas of Phulbani districts,Orissa. *Journal of the Indian Society of Soil Science,***45**(4):724-728.

Divya M, Jagadeesh BR, Srinivasa DK, Yogesh GS (2017). Potassium Fixation and Release Pattern of Soils Under Rice-Cowpea Cropping System of Long-Term Fertilizer Experiment. *Biochem Cell. Arch.* **17**, 147-152.

Haylock OF (1956) A method for estimating the availability of nonexchangeable potassium. *Proceedings of the 6th International Congress of Soil Science*. **Part B**, 402-408.

Keskar DR, Salvi VG, Mayekar BS, Dabke DJ (2001). Forms of Potassium, the interrelationship and Relationships with other soil properties of Inceptisols of West coast of Maharashtra. *Journal of Potassium Research.***17**: 23- 27.

Kumar B, Roy HK, Kumar A (1991). Critical limits of potassium in a soil series. *Journal of the Indian Society of Soil Science*, **39**: 504-508.

Metson AJ (1968) The long-term potassium supplying power of New Zealand soils. *Transaction of 9th International Congress of Soil Science Society. Adelaide, Australia* **2**, 621

Prasad J, Karmakar S, Kumar R, Mishra B (2010). Influence of integrated nutrient management on yield and soil properties in maize-wheat cropping system in an Alfisol of Jharkhand. *Journal of the Indian Society of Soil Science,***58**(2):200-204.

Prasad RE (2003). Effect of levels and methods of potassium application on yield and quality of potato.M.Sc.Thesis. Submitted to SSAC,BAU,Ranchi.

Sekhon GS, Puri DN (1986). The input-output balance of plant nutrients in some multiple cropping systems in India. *Indian Fertilizer News* **21**, 23-27.

Sekhon GS, Brar MS, Subba Rao A (1992). Potassium in Some Bench Mark Soils of India PRII Special Publication No. 3. Potash Research Institute of India, Gurgaon, Haryana.
soil series of India. *Journal of Potassium Research,***15**: 7-18.

Srinivasa Rao C, Ganeshamurthy AN, Ali M (2002). Distribution of forms potassium in different soil type of pulse growing regions of India. *Journal of Potassium Research,* **18**:23-30.

Srinivasa Rao C, Rupab TR, Subba Rao A, Ramesha G, Bansal, SK (2006). Release kinetics of non-exchangeable potassium by different extractants from soils of varying mineralogy and depth, *Soil Science and Plant Analysis*,**37**(3): 473-491.

Subba Rao A, Adinarayana V, Rao IV (1984). Q/I relationship of potassium in representative soils of Andra Pradesh. *J. Indian Soc. Soil. Sci.* **32**, 240-243.the watershed areas of Phulbani districts,Orissa. *Journal of the Indian Society of Soil Science,***45**(4):724-728.

Surekha K, Rao KV (2009). Direct and residual effects of organic sources on rice productivity and soil quality of Vertisols. *Journal of Indian Society of Soil Science,* **57**(1): 53-57.

Surekha K, Subba Rao, Rao IV, Prasad A, Adinarayana V (2006). Long term potassium releasing power of vertisols of Andhra Pradesh. *Journal of Potassium Research*.**12**(4):345-350.