Effect of Long-Term Application of Inorganic Fertilizers, Organic Manure, and Lime on Different Forms of Potassium in Soil under Maize-Wheat Cropping System

Abstract

The field study was undertaken with the major emphasis on potassiumstatus and its percentage contribution in soil as affected by continuous cropping, fertilizer, and manure used over 62 years of crop cycles. The experiment consisted of fourteen treatments replicated thrice in a randomized block design, out of which nine treatments were selected for the present study. The selected treatments werecontrol, T_2-100% N, T_3- FYM, T_4-100% NP, T_5-100% NPK, T_6- 1/2(N+FYM) + P(A-X/2) + K(B-Y/2) (INM), T_7-100% NPK + Lime where the lime application in LR once in 4 years, T_8-Lime+ FYM+ $P_{(A-X)}$ + $K_{(B-Y)}$, T_9-Lime+N. Surface soil (0-15cm) and subsurface soil (16-30 cm) samples were collected after the harvest of wheat in 2017-18 to observe the initial Physico-chemical properties. Different fractions of potassium, viz., water-soluble K, exchangeable K, available K, 1NHNO_3K, non-exchangeable K, Lattice K, and Total K were analyzed for the study. There was a significant difference among the different treatments with respect to potassium fractions in 0-15 cm, and 15-30 cm layers. Moreover, K fractions were significantly decreased with increasing depth of soil. Results showed that the percentage contribution of different forms of K towards the total K in surface soil and subsurface soil followed the order: Lattice K (68.75-78.11%) > Non – Exchangeable K (19.15-25.49%) > Exchangeable K (1.65-2.45%) >Water soluble K (0.18-0.62%). Application of N and P without K caused depletion of soil, water-soluble K, available K, exchangeable K, non-exchangeable K, and lattice K because of continuous removal of potassium content by the crops or leaching action of residual potassium under long term experiment. Therefore, the present investigation stresses the vital importance of the inclusion of organic manure and lime in the fertilizer schedule to maintain soil K dynamics and enhancethe yield of crops so as to sustain soil productivity over the long run under the maize-wheat cropping system.

Keywords: Potassium fractions, Potassium dynamics, inorganic fertilizers, farmyard manure, K uptake, crop yield, soil productivity

1. Introduction

Potassium constitutes an average of 1.9% of the earth's crust and is the third most important essential nutrient required for plant's growth and development. "Being a master and quality cation among nutrients it holds paramount importance with various vital functions. The vital functions are activation of enzymes, osmotic and ionic regulation, homeostatic balance, water and energy relations, stomatal regulations, photosynthesis, assimilation and translocation of photosynthates, sustenance, and sustainability of plants productivity" (Mengel,1985). "The availability of K in the soil is not uniformly distributed as the dynamic nature and interactions of potassium in different chemical forms in soil significantly control its availability to the plants" (Wang *et al*., 2005). "The different dynamic forms of potassium in soil are water-soluble K, the most frequently available form to plants; exchangeable K, held by negative charges on soil colloids and organic matters and is readily available to plants; non-exchangeable-K or fixed K, trapped between layers of expanding lattice clays; and lattice or structural K, an integral part of primary K bearing minerals like mica or illite" (SrinivasaRao*et al*., 2001, Mazumdar*et al*., 2014, Paramita and Chandrasekaran*et al*., 2017). "Water-soluble K has been a dominant fraction in the initial stage while exchangeable and non-exchangeable K contribute more in the later stages of plant growth" (Sharma *et al.*,2009). "The knowledge of various forms of K and its dynamic relationship in the soil is one of the pre-requisite conditions in order to assess the availability to the growing crops and is important for the appraisal of the available K as various pools of K in turn depend on the rate of addition and uptake of K from soil system" (Singh *et al*., 2009). "In most of the intensive cropping systems, the K balance is negative since the additions of K seldom match the K removals resulting in larger dependence on native soil K supply from the mineral reserve (non-exchangeable K pool of soil). Apart from the greater removal of K and leaching loss of K in sandy soil, the predominant use of nitrogenous or phosphatic fertilizers, its widespread availability, relatively low cost, and the quick and evident response of the plants are one of the major reasons for the K imbalance in a country like India" (Sanyal and Chatterjee, 2007). "The rate of Potassium (K) release from soil under an intensive cropping system with long-term application of fertilizer and manuring helps to predict the fate of added K in the soil as well as the nature of K supply from soil to plant and consequently crop yield" (Samra and Swarup, 2001)."The heavy removal of nutrients from the soil by high-yielding varieties for high use of fertilizer made it imperative to examine the sustainability of modern intensive cropping systems based on high external inputs of fertilizers and high-yielding varieties under different cropping systems. Significance of soil fertility maintenance in sustaining crop productivity has been realized worldwide. Sustaining soil quality is the most appropriate method to ensure sufficient food to support life. Maintaining and improving the level of soil organic matter is prerequisite for ensuring soil quality, future productivity and sustainability as it influences soil physical, chemical, biological properties and processes" (Singh 2008). "In addition, being a direct source of plant nutrients, soil organic matter also indirectly influences the availability of plant nutrients in soil from native pools. The balanced fertilization through integrated use of manures and fertilizers has been found useful in various crop sequences. Organic matter in soil is critical for better soil health and higher soil productivity. Continuous application of organic manure is the only way to increase soil organic matter status" (Katyal*etal.* 2001). "A part of nutrient is assimilated by microorganisms and incorporated into microbial biomass. Microorganisms regulate the nutrient flow in the soil by assimilating nutrients and producing soil biomass. The changes in soil organic carbon contents are also directly associated with changes in microbial biomass carbon and biological activity in the soil. Many long-term experiments conducted in India showed increasing yield trends and accumulation of soil organic carbon and biological properties due to combined application of fertilizer and manures" (Manna *et al.* 2005, 2007, Mandal *et al.* 2007, Bhattacharyya *et al.* 2008, 2010, Vineela*et al.* 2008). However, most studies were restricted under irrigated conditions to rice–wheat and soybean–wheat systems. Hence, the knowledge about K reserve in the soil is necessary to understand potassium nutrition and its sustainable management for sustained crop production. With these considerations in view, a field study was conducted to assess the effect of long-term applications of inorganic fertilizers, manuring, and lime on soil K dynamics and their percentage contribution among different forms under an intensive maize-wheat cropping system.

2. Materials and Methods

2.1 Experimental Details

The field study wasas a part of an ongoing Permanent Manurial Trial (PMT) on the maize-wheat cropping system on acidic red loamy soil in 1956 at the Experimental Farm (85^0 19’ E longitude, 23^0 17’ N latitude) of Birsa Agricultural University, Kanke, Ranchi, Jharkhand. The experiment was laid out in Randomized Block Design with 3 replication 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 are 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@ 22t 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), andmuriate 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 K_2O 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 Soil

Initial soil properties were analyzed and studied at the beginning of the experiment as per the standard procedures (Table 2). A total of 54 composite soil samples were collected at two different depths *viz.*,0-15 cm (surface depth) and 15-30 cm (sub-surface depth) after the harvest of the crop from the nine selected treatments replication wise. 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. The water-soluble K was quantified using 1:5 soil: water extraction (Hanway and Heidal, 1952); available K was assessed using neutral normal NH_4OAc at a soil: extractant ratio of 1:5 (Jackson 1973). Exchangeable K was estimated by deducting the value of water-soluble K from available K.NHNO_3 Kwas extracted by using 1 N boiling HNO_3extractant following of the soil: extractant ratio of 1: 8 (Wood and De Turk, 1941). Non – Exchangeable K was estimated by deducting the value of available K from 1N HNO_3 extractable K. Total K was estimated using the HCl extraction method (Jackson, 1973). The difference between total K and1 N HNO_3 extractable K gave the amount of lattice K (Wiklander, 1955).In most of the cases, K concentration was determined using a flame photometer.Besides, plant samples were analyzed for potassium content using the Di-acid extraction method followed by flame photometry and expressed as a percentage on an oven-dry basis. The total uptake of K was worked out by multiplying K content with dry matter production and expressed in kg ha^{-1}.

Table **2: Initial physico-chemical characteristics of the experimental site**

A.	**Physical properties**	
a)	Mechanical Composition	
I.	Sand (%)	45.5
II.	Silt (%)	15.3
III.	Clay (%)	36.4
IV.	Textural Class	Clay loam
b.	Bulk density (Mg m^{-3})	1.45
c.	Specific gravity (Mg m^{-3})	2.67
d.	Total pore space (%)	46.15
e.	Hydraulic conductivity (cm hr^{-1})	3.7
B.	**Physico-Chemical properties**	
pH		5.5
C.E.C (c mol (p+) kg^{-1})		10.5
Exch.Ca^{+2} (c mol (p+) kg^{-1})		6.0
Exch.Mg^{+2} (c mol (p+) kg^{-1})		2.5
Exch.K^{+} (c mol (p+) kg^{-1})		1.16
Exch.K^{+} (c mol (p+) kg^{-1})		0.26
Electrical conductivity (dSm^{-1})		0.03
C.	**Chemical properties**	

Organic carbon (g kg^{-1})	0.52
Available P (mg kg^{-1})	7.5
1NHN0_3 –K(mg kg-^{1})	790
Total K(mg Kg^{-1})	3720
1NH4OAC-K (mg kg^{-1})	360
Water-soluble K (mg kg^{-1})	30

2.3 Statistical Analysis

The significant difference among the treatments was analyzed by using Duncan'sMultiple Range Test as described in Gomez and Gomez (1984). Treatment means were compared at 5% level of significance.

3. Results and Discussion

3.1Different forms of K Under Long Term Effect of Nutrient Management Practices

3.1.1 Water Soluble K

Under different nutrient-management treatments, the concentration of water-soluble K in the surface soil ranged from6.4 to 24.24 kg ha^{-1}, and in the sub-surface soil ranged from 6.03 to 23.91 kg ha^{-1}.In sub-surface soil, the water-soluble K was numerically lower than in the surface soils. The significantly highest water-soluble K in surface soil was observed with a full dose of Lime, FYM, P_2O_5, and K_2O fertilizers (T_8) than other treatments followed by lime + NPK (T_7). The treatment $T_7$is at par with T_8 and both are significantly superior to the rest of the treatment. This could be attributed to the release of labile K from organic residues, application of K containing fertilizers, stimulating effect of FYM in reducing K fixation,and upward translocation of K from lower soil depths with the capillary rise of groundwater (Ranganathan and Satyanarayan, 1980, Lakaria *etal*., 2012, Mazumdar*et al*., 2014). While the significantly lowest water-soluble K was observed in $T_4$with 100 % NP. This might be due to continuous cropping, and relatively higher crop uptake without the addition of K for the last 62 years (Paramita Rout *et al*., 2017). A similar trend was also observed in sub-surface soil.

3.1.2 Exchangeable K

The concentration of Exchangeable K in the surface soil ranged from 56.5 to 200.76 kg ha^{-1} and in the sub-surface soil ranged from 51.67 to 195.89 kg ha^{-1}.The highest Exchangeable K status was 200.76 kg ha^{-1}in surface soil when the plot was treated with a full dose of Lime, FYM, P_2O_5, and K_2O fertilizers(T_8) which were significantly higher than other treatments while the lowest concentration was observed in $T_4$with 100 % NP."The higher amounts of exchangeable K in the FYM treated plots over the years may be due to the fact that FYM addition could increase the CEC of soil which was responsible for holding more amount of exchangeable K and help in the release of exchangeable K from the non-exchangeable pool, consequenttoa mass action effect" (Black 1968, Yaduvanshi and Swarup, 2006). Bhattacharyya *etal.*,(2006)reported that "a higher amount of K is attributed to the process of structural K release through increasing the area of exchangeable surfaces, and due to the acceleration weathering of the interlayer K by application of FYM". "The higher concentration of Exchangeable K under K fertilized plots in surface soil could be attributed to the addition of K through plant residues, manure, and fertilizers" (Sharma *et al.*, 2009,Jadhao*et al*., 2018). "Application of a full dose of Lime, FYM, P_2O_5, and K_2O fertilizers(T_8) resulted in a significant increase in the exchangeable K content over all the treatments in both depths.This effect can be attributed to the movement of added K to exchange sites from the soil solution and to an increase in the K concentration in the soil solution" (Dhanrokar et al., 1994)."It was also observed that the Exchangeable K of 100% NP treated plot (T_4) was significantly lower (51.67 kg ha^{-1}) than all the treatments. However, the concentration of exchangeable K was numerically lower in subsurface soil as compared to surface soil in all the treatments which may be due to comparatively more weathering vegetation and supply of K from organic residues in the surface layer in lower depth" (Sharma *et al.*, (1994) and Mazumdar*et al.*, (2004).

3.1.3Available K

The concentration of Available K ranged from 62.9 to 225 kg ha^{-1} in the surface soil and 57.7 to 219.8 kg ha^{-1} in the sub-surface soil. The significantly highest water-soluble K in surface soil was observed with a full dose of Lime, FYM, P_2O_5, and K_2O fertilizers (T_8) than other treatments followed by 100 % NPK (T_5) and both (T_8) and (T_5) significantly superior over other treatments.This may be due to the stimulating effect of FYM in reducing K fixation, thereby bringing more K into available form (Jatav*et al*., 2010). As FYM act as a reservoir of potassium and continuous release of K during decomposition increased the available K content significantly (Kher and Minhas (1991). FYM is not only a direct but ready source of K but also aids in minimizing the leaching loss of K by retaining K ions on exchange sites of its decomposed products (Bansal and Sckhon 1992 and M. Divya*et al*., 2016).It was also observed that the Available K of 100% NP treated plot (T_4) was significantly lower (62.9 kg ha^{-1}) than all the treatments. On critical examination of data presented in Table 4, soil available K is lower in sub-surface soil as compared to the surface layer.It was also observed that available K of both depths followed a similar pattern.

3.1.4 1NHNO$_3$K

On critical analysis under different nutrient-management treatments,the concentration of 1NHNO$_3$ Kin the surface soil ranged from 710 to 1222 kg ha^{-1}.The 1NHNO$_3$ K status was 1222 kg ha^{-1} (T_8), when the plot was treated with (Lime, FYM, P_2O_5, and K_2O fertilizers) which was significantly higher than other treated plots followed by ½ (N+FYM) + $P_{(A-X/2)}$ + K $_{(B-Y/2)}$(T_6) which is 1050.7 kg ha^{-1}. This might be due to the greater application of potassium in the form of 100% K_2O+ FYM than others, stimulating the effect of FYM in reducing K fixation, thereby bringing in more K into available form(Jatav*et al*., 2010).FYM act as a reservoir of potassium and continuous release of K during decomposition increased the available K content significantly (Kher and Minhas, 1991). Farmyard manure is not only a direct but ready source of K but also aids in minimizing the leaching loss of K by retaining K ions on exchange sites of its decomposed products (Bansal and Sckhon 1992)and M. Divya*et al*. (2016). While the significantly lower 1NHNO$_3$ K(710.7 kg ha^{-1}) was observed in the control plot (T$_1$) compare to all the treatments. This may be due to continuous cropping without the addition of K for the last 62 years. In the case of subsurface soil, the range varies from 702.7 to 1212.3 kg ha^{-1}.On critical examination of data, it was also observed that 1NHNO$_3$K was decreased in sub-surface (16-30 cm) soil than in surface (0-15 cm) soil, and 1NHNO$_3$ K of surface and sub-surface soil followed the same trend.

3.1.5 Non-exchangeable K

The concentration of Non-exchangeable Kin the surface soil ranged from 622 to 997 kg ha^{-1} and in the sub-surface soil ranged from 618.5 to 992.5 kgha^{-1}. In surface soil, theplot was treated with FYM, P_2O_5, and K_2O fertilizer(T$_8$)which was significantly higher(997 kg ha^{-1}) than other treated plots and followed by INM(T$_6$) treated plot (935 kg ha^{-1}). Continuous application of increasing levels of potassic fertilizer maintained the content ofnon-exchangeable K at a higher level. The non-exchangeable K content was lower inof control plot(622kgha^{-1})and 100% N treated plot (669 kg ha^{-1})because of higher K uptake and accumulation of organic matter.The greater depletion of non-exchangeable K in presence of organic matter could be due to the accumulation of organic matter. there would be a shift in CEC sites towards divalent selectivity (Salmon, 1964), which would decrease the percentage K saturation of CEC, resulting in the shift of equilibrium of non-exchangeable K to exchangeable K in favor of the latter, thereby releasing more non-exchangeable K (Mazumdar*et al*., (2014). While the concentration of Non-exchangeable K in the sub-surface soil ranged from 618.5 to 992.5 kgha^{-1}. The Non-exchangeable K status was 992.5kg ha^{-1} (T$_8$) when the plot was treated with a full dose of Lime+ FYM+P (A-X+K(B-Y)fertilizers which were significantly higher than other treatments. It was followed by INM (T$_6$) treated plot (1041 kgha^{-1}). On critical examination of data, it was also observed that the non-exchangeable K content was numerically lower in the subsurface than in surface soils, which could be due to fertilizer addition in the surface soil layer due to greater clay content in surface soil that might have retained much of applied K (Datta 2005).

3.1.6 Lattice K

The concentration of Lattice K in the surface soil ranged from 2521 to 3306 kg ha^{-1}. The highest lattice K was 3306 kg ha^{-1} (T$_6$) when the plot was treated with INM fertilizers dose (FYM, P_2O_5,K_2O) which was found at par with the treatment T$_7$(3155) followed by T$_5$ (3105) & T$_3$(2934). Whereas, Lattice K of 100% N treated plot (T$_2$) was significantly lower (2521 kg ha^{-1}) than all the treatments. The control, 100% N, 100% NP, and Lime + N treatments were found to be at par with each other and significantly lower than FYM, 100% NPK, INM, 100% NPK + Lime, and Lime + FYM+P+K treated plot.The amount of lattice K in the absence of K fertilization slower shifts in equilibrium to compensate for crop removal and translocation of clays as reported by Das *et al.*, (1993). A perusal of Lattice K under different nutrient-management treatments, the concentration of Lattice K in the sub-surface (16-30 cm) soil ranged from 2465 to 3240 kg ha^{-1}.The Lattice K status was 3240 kg ha^{-1}(T$_6$) when the plot was treated with INM fertilizers which were significantly higher than other treatments. It was followed by

100 % NPK, Lime (T_7) treated plot (3107 kg ha^{-1})and at par with T-3(2905), T-5 (3049 kg ha^{-1} respectively). It was also observed that Lattice K of 100 % N treated plot (T_2) was significantly lower (2465 kg ha^{-1}) than all the treatments. On critical examination of data, it was also observed that Lattice K was decreased in sub-surface (16-30 cm) soil than in surface (0-15 cm) soil. Lattice K of surface and sub-surface soil followed the same trend.

3.1.7 Total K

The concentration of Total K in the surface soil ranged from 3248 to 4357 kg $ha^{-1}$and in the sub-surface soil ranged from 3191 to 4281 kg ha^{-1}. The highest total K was found in the plot treated with INM fertilizers dose (FYM,P_2O_5,K_2O)which was significantly higher than all the other treatments followed by 100% NPK+ Lime(T_7) treated plot(4109 kg ha^{-1})and at par with 100% NPK (T_5) (4050 kg ha^{-1}) and significantly higher than other treatments(T_1-3248,T_2-3315, T_3- 3805, T_4- 3394, T_8-23911.4,T_9-3344.2 kg ha^{-1}). It was also observed that the Total K of the control plot (T_1) was significantly lower (3248 kg ha^{-1}) than all the treatments. The exclusion of K fertilizers from the fertilization schedule (100% N, 100% NP & Lime + N) decreased the total K content in the soil which is comparable to unfertilized control. This may be due to continuous removal by crop without compensating the K pools through an external supply of K fertilizers. The total K content was found to increase with graded doses of fertilizers.It can be assumed that FYM contains 0.5% K, this additional application of K through FYM may have contributed to increased total K in treatment receiving INM,100% NPK + FYM &Lime +FYM+P+K(Santhy, 1995). In the case of sub-surface soil, The Total K status was 4281kg ha^{-1} (T_6), when the plot was treated with INM fertilizers which were significantly higher than other treatments. Itwas followed by INM (T_7) treated plot (4053kg ha^{-1}) which was at par with the treatment-6 (4281kg ha^{-1}) treated plot. It was also observed that the Total K of the control plot (T_2) was significantly lower (2465 kg ha^{-1}) than all the treatments.On critical examination of data, it was also observed that Total K was decreased in sub-surface (16-30 cm) soil than in surface (0-15 cm) soil. It was also observed that available K of both depths followed the same trend.

4.Percentage of different forms of potassium in soil under maize-wheat cropping system

The proportion of different K forms of potassium to total K revealed that Lattice K occupies the highest percentage of total K (68.7-78.11%)followed by Non-exchangeable K (19.15 - 25.49 %), Exchangeable K(1.65 - 2.45 %), and Water-soluble K (0.18 - 0.62 %). A similar observation was also reported by Pasricha (2002) and also reported by Singh and Bansal(2009).For different soils,the contribution of different forms of K to total K (Table- 7) showed that the lattice K contributedthe highest (78.11%) to total K followed by non-exchangeable K (25.49%), available K (5.75%), Exch-K (5.13%) and water-soluble K(WSK) (0.62%) is indicating the dominance of fixed forms of K in the soil. Pascricha (2002) reported that a major portion of soil K exists as part of the mineral structure and in a fixed or NEK form with a small fraction as WSK and exchangeable -K in soil. The sequential order of dominance of different forms of K in this study was in the order: lattice K > Non Exch-K >Exch-K > WSK. The highest value of K fractions was recorded in the treatments 100 NPK and 100% NPK + FYM. A similar trend inthe relative contribution of different forms of K to total K was observed by Jatav*et al*., (2010).Long term effects of different nutrient management practices on different forms of potassium were significantly affected (Table-7).

Table-3: Effect of nutrient management practices on different forms of available K in surface soil after 62 crop cycles.

Surface soil 0-15 cm				
Treatments		**Water soluble K (kg ha^{-1})**	**Exchangeable K (kg ha^{-1})**	**Available K (kg ha^{-1})**
T_1	Control	9.14	79.56	88.7
T_2	100 % N	13.8	111.3	125.1
T_3	FYM	11.5	98.23	109.7
T_4	100 % NP	6.40	56.5	62.9
T_5	100 % NPK	14.89	116.11	131
T_6	½ (N+FYM) + P (A-X/2) + K (B-Y/2) (INM)	12.63	103.07	115.7
T_7	100 % NPK + Lime	20.90	83.6	104.5
T_8	Lime +FYM+P(A-X)+K(B-Y)	24.24	200.76	225
T_9	Lime + N	8.23	67.27	75.5
CD(P=0.05)		**0.90**	**3.85**	**4.04**
CV(%)		**4.37**	**2.23**	**2.09**

Table- 4: Effect of nutrient management practices on different forms of available K in sub-surface soil after 62 crop cycles.

Sub-surface soil 16-30 cm				
Treatments		**Water soluble K(kg ha^{-1})**	**Exchangeable K (kg ha^{-1})**	**Available K (kg ha^{-1})**
T_1	Control	8.67	75.53	84.2
T_2	100 % N	12.85	106.85	119.7
T_3	FYM	11	93.47	104.6
T_4	100 % NP	6.03	51.67	57.7
T_5	100 % NPK	13.3	113	126.3
T_6	½ (N+FYM) + P (A-X/2) + K (B-Y/2) (INM)	12.11	98.39	110.5
T_7	100 % NPK + Lime	20.45	76.95	97.4
T_8	Lime +FYM+P(A-X)+K(B-Y)	23.91	195.89	219.8
T_9	Lime + N	8.10	63.2	71.3
CD(P=0.05)		**0.97**	**5.60**	**5.72**
CV(%)		**4.84**	**3.35**	**3.06**

Table-5: Effect of nutrient management practices on different forms of K in surface soil at the end of 62 crop cycles.

Surface soil 0-15 cm					
Treatments		**1NHNO_3 K (kg ha^{-1})**	**Non-exch. K (kg ha^{-1})**	**Lattice K (kg ha^{-1})**	**Total K (kg ha^{-1})**
T_1	Control	710.7	622	2537	3248
T_2	100 % N	794.1	669	2521	3315
T_3	FYM	870.73	761	2934	3805
T_4	100 % NP	765.9	703	2628	3394
T_5	100 % NPK	945	814	3105	4050
T_6	½ (N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$ (INM)	1050.7	935	3306	4357
T_7	100 % NPK + Lime	954.5	879	3155	4109
T_8	Lime +FYM+P(A-X)+K(B-Y)	1222	997	2689	3911.4
T_9	Lime + N	762.5	687	2582	3344.2
CD(P=0.05)		**11.38**	**12.06**	**229.39**	**229.80**
CV(%)		**0.73**	**0.88**	**3.61**	**0.35**

Table-6: Effect of nutrient management practices on different forms of K in sub-surface soil at the end of 62 crop cycles.

Sub-surface soil 16-30 cm					
Treatments		**1NHNO_3 K (kg ha^{-1})**	**Non-exch. K (kg ha^{-1})**	**Lattice K (kg ha^{-1})**	**Total K (kg ha^{-1})**
T_1	Control	702.7	618.5	2488	3191
T_2	100 % N	785	665.3	2465	3250
T_3	FYM	861.5	757	2905	3766
T_4	100 % NP	756.5	698.8	2570	3326
T_5	100 % NPK	945.8	819.5	3049	3995
T_6	½ (N+FYM) + P$_{(A-X/2)}$ + K $_{(B-Y/2)}$ (INM)	1041	930.5	3240	4281
T_7	100 % NPK + Lime	945.9	850	3107	4053
T_8	Lime +FYM+P(A-X)+K(B-Y)	1212	992.5	2631	3843
T_9	Lime + N	754.6	683.3	2533	3288
CD(P=0.05)		**12.27**	**10.61**	**444.67**	**440.56**

CV (%)	**0.79**	**0.78**	**0.71**	**0.69**

Table-7: Long term effect of nutrient management practices on different forms of potassium in soil after harvest of wheat

Treatments		**Water soluble K** (kg ha^{-1})		**Exchangeable K** (kg ha^{-1})		**Available K** (kg ha^{-1})		**1NHNO$_3$ K** (kg ha^{-1})		**Non-Exch.K** (kg ha^{-1})		**Lattice K** (kg ha^{-1})		**Total K** (kg ha^{-1})	
		0-15	**16-30 cm**	**0-15**	**16-30 cm**	**0-15**	**16-30 cm**	**0-15**	**16-30 cm**	**0-15**	**16-30 cm**	**0-15**	**16-30 cm**	**0-15**	**16-30 cm**
T_1	Control (kg/ha)	9.14 (0.28)	8.67 (0.27)	79.56 (2.45)	75.53 (2.37)	88.70 (2.73)	84.20 (2.64)	710.7 (21.88)	702.7 (22.02)	622 (19.15)	618.5 (19.38)	2537 (78.11)	2488 (77.96)	3248	3191
T_2	100 % N	13.80 (0.42)	12.85 (0.40)	111.3 (3.36)	106.85 (3.29)	125.1 (3.77)	119.17 (3.68)	794.1 (23.96)	785 (24.15)	669 (20.18)	665.3 (20.47)	2521 (76.05)	2465 (75.85)	3315	3250
T_3	FYM	11.50 (0.30)	11 (0.29)	98.23 (2.58)	93.47 (2.48)	109.7 (2.89)	104.6 (2.78)	870.73 (22.88)	861.47 (22.88)	761 (20)	757 (20.10)	2934 (77.10)	2905 (77.14)	3805	3766
T_4	100 % NP	6.40 (0.19)	6.03 (0.18)	56.50 (1.66)	51.67 (1.55)	62.9 (1.85)	57.7 (1.73)	765.9 (22.57)	756.5 (22.75)	703 (20.71)	698.8 (21.01)	2628 (77.43)	2570 (77.27)	3394	3326
T_5	100 % NPK	14.89 (0.37)	13.30 (0.33)	116.11 (2.87)	113 (2.83)	131 (3.23)	126.3 (3.16)	945 (23.33)	945.8 (23.68)	814.8 (20.10)	819.5 (20.51)	3105 (76.67)	3049 (76.32)	4050	3995
T_6	½ (N+FYM) + P (A-X/2) + K (B-Y/2) (INM)	12.63 (0.29)	12.11 (0.28)	103.07 (2.37)	98.39 (2.30)	115.7 (2.66)	110.5 (2.58)	1050.7 (24.11)	1041 (24.32)	935 (21.46)	930.5 (21.74)	3306 (75.88)	3240 (75.68)	4357	4281
T_7	100 % NPK + Lime	20.90 (0.50)	20.45 (0.50)	83.60 (2.03)	76.95 (1.90)	104.5 (2.54)	80.9 (2.0)	954.5 (23.23)	945.9 (23.34)	879 (21.39)	875 (21.59)	3155 (76.78)	3107 (76.66)	4109	4053
T_8	Lime +FYM+P(A-X)+K(B-Y)	24.24 (0.62)	23.91 (0.62)	200.76 (5.13)	195.89 (5.1)	225 (5.75)	219.8 (5.72)	1222 (31.24)	1212.3 (31.55)	997 (25.49)	992.5 (25.83)	2689 (68.75)	2631 (68.46)	3911	3843
T_9	Lime + N	8.23 (0.25)	8.10 (0.25)	67.27 (2.01)	63.20 (1.92)	75.5 (2.26)	71.3 (2.17)	762.5 (22.80)	754.6 (22.95)	687 (20.54)	683.3 (20.78)	2582 (77.20)	2533 (77.03)	3344	3288
CD (P = 0.05)		**0.90**	**0.97**	**3.85**	**5.60**	**4.04**	**5.72**	**11.38**	**12.27**	**12.06**	**10.61**	**229.39**	**444.68**	**229.80**	**440.56**
CV(%)		**4.37**	**4.84**	**2.23**	**3.35**	**2.09**	**3.06**	**0.73**	**0.79**	**0.88**	**0.78**	**3.61**	**0.71**	**0.35**	**0.69**

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Figures in percentage indicate % contribution

6. Conclusion

The results obtained from the study on long-term fertilization under maize-wheat cropping systems revealed that application of T_8-Lime+ FYM+ $P_{(A-X)}$ + $K_{(B-Y)}$, T_9-Lime+N(T_8) followed by 100% NPK+ Lime($T_{7)}$significantly contribute higher potassium than rest of the treatment and improved potassium fractions in soil over control.Therefore, the present investigation stresses the vital importance of the application of chemical fertilizers in conjunction with organic manures and lime in the fertilizer schedule in exploiting the high yield potential of crops through its favourable effect on K supply and maintaining soil K dynamics as because neither organic manure sources alone nor mineral fertilizers can achieve sustainability in crop productivity under intensive cropping sequence, where nutrient turnover in soil plant system is much higher in order to sustain soil productivity over the long run.Since many long-term experiments conducted in India showed increasing yield trends and accumulation of soil organic matter which influences the physico-chemical and biological properties and nutrient dynamics of soil due to combined application of fertilizer and manures without consideration of the vital importance of lime application. However, most studies were restricted under irrigated conditions to rice–wheat and soybean–wheat systems. Hence the integrated application of lime, organic manures and chemical fertilizers under maize-wheat cropping systems can be a suitable option for future perspective in order to maintain the various forms of potassium under nutrient dynamics of soil.

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8. Conflict of Interests

Authors have declared that no competing interests exist.

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