



Effect of Long-Term Manuring and Fertilization on Depth Wise Distribution of Potassium Fractions under Sorghum-Wheat Cropping Sequence in Vertisol

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The effect of long-term manuring and fertilization on depth-wise distribution of potassium (K) fractions under sorghum-wheat cropping sequence in Vertisols was studied under the long-term fertilizer experiment (AICRP's) at Akola, Maharashtra. The treatments comprised of 50% NPK, 100% NPK (P applied through SSP), 150% NPK, 100% NPK(-S), 100% NPK + Zn @ 2.5 kg ha⁻¹, 100% NP, 100% N, 100% NPK + FYM @ 5 t ha⁻¹, 100% NPKS, FYM @ 10 t ha⁻¹ to sorghum and wheat, 75% NPK + 25% N through FYM and Control laid out in randomized block design. The results of the present study revealed that, application of 100% NPK + FYM @ 5 t ha⁻¹ significantly increased the fractions of K viz., available K (210 mg kg⁻¹), water soluble K (8.75 mg kg⁻¹), exchangeable K (201 mg kg⁻¹), non-exchangeable K (945 mg kg⁻¹) and lattice K (17078 mg kg⁻¹) in 0-15 cm depth. Similar trends in K fractions were also noted in 15-30 and 30-45 cm depths. The sequential order of dominance of different fractions of K were: lattice K > non-exchangeable K > exchangeable K > available K > water soluble K. The highest negative balance of K was recorded with the application of 100% NP (-3513 kg ha⁻¹) followed by 100% NPK + FYM @ 5 t ha⁻¹ (-3110 kg ha⁻¹) and 150% NPK (-2838 kg ha⁻¹). The application of NPK + FYM (470 kg ha⁻¹), 150% NPK (432 kg ha⁻¹) and 100% NPK (378 kg ha⁻¹) resulted in improving the status of available K over its initial (358 kg ha⁻¹) status. The grain yield of sorghum and wheat was influenced significantly with the application of NPK + FYM (5.27 and 3.39 t ha⁻¹) followed by 150% NPK (4.87 and 3.21 t ha⁻¹). The SYI of the system was improved with NPK + FYM as compared to control for sorghum (-0.008) and wheat (0.004). The contribution of non-exchangeable K to total uptake was higher in NP (3316 kg ha⁻¹) followed by NPK + FYM (3060 kg ha⁻¹). All the K forms showed significant and positive correlation with yield and uptake of K. There exists a significant and positive correlation indicating dynamic equilibrium among all forms of K.

Key words: Potassium fractions, sorghum-wheat sequence, FYM, SYI, grain yield

Heavy dose of chemical fertilizers coupled with high yielding varieties unlikely to sustain long-term productivity of the sorghum-wheat cropping systems in swell-shrink soils of Vidarbha. Potassium (K) is one of the nutrients of special importance for crop production under rainfed conditions in this region. Potassium, a component of several minerals, is released to soluble and exchangeable forms by weathering of these minerals at widely differing rates. Soil potassium exists in dynamic equilibrium in four forms viz., water soluble (WSK), exchangeable (Exch-

K), non-exchangeable (NEK) and lattice K, of which the first two are important for the growth of higher plants and microbes (Singh *et al.* 2010). A large portion of the total K in soil occurs as structural component of soil minerals and is unavailable to plants. Plants can use only the Exch-K present on the surface of soil particles and the K dissolved in soil water. This often constitutes very small fraction of the total soil K. The dynamics of K in soil depends on the magnitude of equilibrium among various forms which have relationship with physicochemical properties (Sharma *et al.* 2009). Under intensive cultivation, readily available K is removed by crop. This is followed by further release of Exch-K from

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non-exchangeable forms. The level of soil solution K depends upon equilibrium and kinetic reactions that occur between different forms of soil K, the soil moisture content and the concentration of bivalent cations in solution and exchange phase (Sparks and Huang 1985). Continuous mining of native soil K and the decline in available K highlight the need to re-examine the current fertilizer K recommendation for different cropping systems on different soils to arrest the decline in native K fertility and improve sustainability of production system. Various attempts had been made to assess the status of K, its availability in different fractions and balance under maize- wheat sequence in acid Alfisol (Sood *et al.* 2008), rice-wheat sequence on Aquic Natrustalf (Yaduvanshi and Swarup 2006), finger millets on K deficient Alfisol (Srinivasarao *et al.* 2014), rice-wheat on Mollisol (Singh *et al.* 2014) and soybean-wheat on Vertisol (Sawarkar *et al.* 2013). However, in the present study, an attempt has been made to assess the effect of long-term manuring and fertilization on depth-wise distribution of various fractions of K under sorghum-wheat cropping sequence in Vertisol.

Materials and Methods

A long-term fertilizer experiment was initiated at the research farm of the department of soil science and agricultural chemistry in Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (22°42' N, 77°02' E at an altitude of 307.42 m above mean sea level), Maharashtra during 1988-89. It represents Agro Ecological Region No. 6.3 and sub-region number – K5Dm4, eastern Maharashtra Plateau, hot moist, semi-arid ESR with medium and deep clay black soils (shallow loamy to clayey black soils as intrusions), medium to high available water holding capacity (AWC) and length of growing period (LGP) between 120-150 days, the period during which the availability of moisture in the root zone of a crop is adequate to meet the water needs. It depends upon the AWC and type of soil interacting with a given quantity on rainfall. The experiment comprised twelve treatments replicated four times in RBD. The soil of experimental site was deep, clayey black soil taxonomically classified as very fine, smectitic, calcareous, hyperthermic family of Typic Haplusterts. The soil is having low hydraulic conductivity and high water holding capacity. The initial analysis indicated that, soil is slightly alkaline in reaction (pH 8.1) and are low in organic carbon (OC) (4.6 g kg⁻¹) and available N (120 kg ha⁻¹), very low in available P (8.40 kg ha⁻¹)

and high in available K (358 kg ha⁻¹). The experimental soil was slight to marginal deficient in S (11.8 mg kg⁻¹) and Zn (0.62 mg kg⁻¹). The treatments consisted of 50% NPK (T₁), 100% NPK (P through SSP) (T₂), 150% NPK (T₃), 100% NPK(-S) (T₄), 100% NPK + Zn @ 2.5 kg ha⁻¹ to wheat only (T₅), 100% NP(-K) (T₆), 100% N (-PK) (T₇), 100% NPK + FYM @ 5 t ha⁻¹ to sorghum only (T₈), 100% NPK + S @ 37.5 kg ha⁻¹ (T₉), FYM @ 10 t ha⁻¹ to sorghum and wheat (T₁₀), 75% NPK + 25% N through FYM (T₁₁) and control (T₁₂). The 24th cycle of the experiment during 2011-12 was studied in the present investigation. The recommended dose of fertilizer as 100:50:40 kg N, P₂O₅ and K₂O ha⁻¹ applied to sorghum while 120:60:60 N, P₂O₅ and K₂O kg ha⁻¹ to wheat. The FYM (0.50% N, 0.16% P and 0.52% K) was added on dry basis before sowing of sorghum whereas, half dose of N and full dose of P and K was applied at the time of sowing to sorghum and remaining half dose of N was applied 30 days after sowing. The half dose of N and full dose of P and K was applied at the time of sowing to wheat and remaining half dose of N was applied 21 days after sowing. Soil samples were collected plot-wise representing 0-15, 15-30 and 30-45 cm depth after harvest of wheat during 2011-12 (24th cycle) and air-dried, processed and analyzed for WSK, Exch-K, NEK and total K. Available K was determined by neutral normal ammonium acetate extraction method using flame photometer (Jackson 1973), WSK was extracted by shaking the soils with water in 1:5 (soil: water) ratio for five min. Exchangeable K was obtained by subtracting the WSK from available K. Non-exchangeable K was determined by treating with 1 N HNO₃ in 1:10 ratio and boiling for 10 min (Wood and De Turk 1941). Lattice-K was calculated from the difference between total K and the sum of NH₄OAc-K and non-exchangeable K (Wiklander 1954). Total K in soil was analyzed by digesting the soil samples with a HF-HClO₄ mixture using platinum crucibles following the procedure outlined by Pratt (1965). Potassium in all the extracts was estimated flame photometrically. The results obtained were statistically analyzed following Gomez and Gomez (1984).

The contribution of non-exchangeable K to total K uptake of crops was determined by following relationship (Srinivasarao *et al.* 2014):

Contribution of non-exchangeable K (kg ha⁻¹) = (Total K uptake by sorghum and wheat + available K after 24th cropping cycle) – fertilizer K addition – initial K status

Per cent contribution =

$$\frac{\text{Contribution of non-exchangeable K (kg ha}^{-1}\text{)}}{\text{Total K uptake (kg ha}^{-1}\text{) by sorghum and wheat}} \times 100$$

For calculating the sustainability yield index (SYI) (Sharma *et al.* 2004) the following equation was used:

$$SYI = \frac{\bar{Y} - \sigma}{Y_{\max}}$$

Where,

\bar{Y} = Average yield of the treatment

σ = Treatment standard deviation

Y_{\max} = Maximum yield in the experiment over the years

Results and Discussion

Vertical distribution of potassium forms

Available K comprises of exchangeable and water soluble K. In some instances, K may be available from fixed state to a substantial degree. The available K was larger in surface layer (0-15 cm) and remained more or less uniform in the other two layers. The available K status ranged from 77.8 to 209.7, 78.5 to 201.7 and 83.3 to 197.8 mg kg⁻¹ in 0-15, 15-30 and 30-45 cm depths, respectively (Table 1). The application of 100% NPK + FYM @ 5 t ha⁻¹ recorded significantly highest available K (209.7 mg kg⁻¹) followed by 150% NPK (192.8 mg kg⁻¹). The build-up of soil available K due to application of 100% NPK along with FYM may be due to solubilizing action of certain organic acids produced during decomposition and greater capacity to hold K in the available form. Yaduvanshi *et al.* (2013) reported that available K increased in treatments receiving green manure (GM) or FYM with 120-26-42 kg ha⁻¹ NPK. Kumar *et al.* (2007) reported that addition of inorganic along with organics showed an improvement in the build-up of K whereas omission of fertilizer K and organics did not exhibit profound influence on status of K. The application of K in balanced dose to the sequence, resulted improvement in the status of available K, whereas, continuous cropping of sorghum –wheat devoid of fertilizer K drastically reduced the available K, indicating an input of about 100 kg K ha⁻¹ is required to maintain the initial K status.

The results pertaining to WSK are presented in table 1. The WSK or soil solution K is the form of K that is directly taken up by plants and microbes and also is the form subject to most leaching in soil. In general, the WSK was decreased with an increase in the depth of soil from 0-15 cm (3.72 to 8.75 mg kg⁻¹),

Table 1. Effect of long-term manuring and fertilization on vertical distribution of potassium fractions in soil

Treatments	Potassium fractions (mg kg ⁻¹)																	
	Available -K			Water soluble-K			Exchangeable-K			Non-exchangeable-K			Lattice K		Total K			
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
50% NPK	120.0	114.2	111.0	6.57	6.32	6.21	113.4	107.9	104.8	769	745	763	12864	11957	12442	13734	12816	13316
100% NPK	168.6	163.2	150.8	6.99	6.66	6.57	161.7	156.6	144.3	824	816	819	14167	13637	13156	15160	14617	14123
150% NPK	192.8	191.9	188.2	8.40	8.06	7.95	187.5	183.6	180.3	912	909	908	16763	16297	15728	17871	17398	16824
100% NPK (-S)	166.0	161.9	146.8	6.94	6.74	6.60	159.1	155.2	140.2	836	832	833	13143	12214	12749	14145	13208	13729
100% NPK + Zn	172.4	165.6	155.2	7.02	6.88	6.66	165.4	158.7	148.6	850	843	847	14296	13463	13832	15320	14473	14835
100% NP	100.6	105.4	110.1	4.70	4.81	4.98	95.9	100.6	105.0	703	709	714	7337	7618	7926	8107	8432	8750
100% N	97.9	102.7	106.3	4.13	4.33	4.56	93.7	98.3	101.8	669	674	683	7047	7394	7588	7814	8171	8378
100% NPK + FYM	209.7	201.7	197.8	8.75	8.45	8.34	201.0	193.2	189.4	944	943	941	17078	16752	16193	18233	17897	17333
100% NPK + S	170.0	165.3	154.1	7.22	6.96	6.80	162.8	158.3	147.3	793	788	791	14626	14236	14367	15590	15190	15313
FYM @ 10 t ha ⁻¹	131.9	124.9	121.4	6.33	6.21	6.05	125.6	118.7	115.3	761	759	760	11818	11427	10917	12712	12323	11799
75% NPK + 25% N through FYM	146.1	135.8	131.6	6.88	6.63	6.43	139.2	129.2	125.2	798	788	785	14006	13614	13613	14950	14539	14080
Control	77.8	78.5	83.3	3.72	3.83	4.02	74.1	74.7	79.2	622	641	657	6445	6751	7071	7145	7471	7811
CD (P=0.05)	2.8	2.8	2.8	0.24	0.30	0.28	2.86	2.84	2.76	11	12	9	106.78	106.52	106.27	120.7	112.2	103.7

15-30 cm (3.83 to 8.45 mg kg⁻¹) and 30-45 cm (4.02 to 8.34 mg kg⁻¹). Significantly highest WSK was recorded with the application of 100% NPK + FYM @ 5 t ha⁻¹ (8.75 mg kg⁻¹) followed by 150% NPK (8.40 mg kg⁻¹) as compared to other treatments indicating greater release of K into soil solutions. The findings are in accordance with Yaduvanshi and Swarup (2006). Such increased status of available and solution forms of K with NPK + FYM may be due to stimulating effect of FYM in reducing K fixation, thereby bringing in more K into available form. Similar results have also been reported by Jatav *et al.* (2010) under potato-radish sequence in sandy loam soils. The higher available and WSK value in surface layer could be due to cultivation practices and higher organic matter content, application of K-bearing fertilizers and upward translocation of the element from lower depth with capillary rise of ground water. Similar type of distribution pattern was reported by Singh *et al.* (2002) under continuous rice-wheat sequence in Vertisol. On the contrary, the treatments, which could not receive K (NP or N) since 24 years showed slight increase in WSK with depths indicating continuous removal of solution K by crops and leaching without any external addition. The extent of decrease in WSK due to omission of K (100% NP) in comparison to 100% NPK was recorded to the tune of 33, 28 and 24 per cent in 0-15, 15-30 and 30-45 cm depths, respectively. These results can be expected in Vertisols developing shallow to deep cracks and exhibiting intermixing of surface and sub-surface soils. The results are in accordance with the finding of Singh *et al.* (2006).

Exchangeable-K has been regarded as reliable index of K removal by crops. It is held by the negative charges of organic matter and clay minerals. The Exch-K content in 0-15, 15-30 and 30-45 cm depths ranged between 74.1 to 201.0, 74.7 to 193.2 and 79.2 to 189.4 mg kg⁻¹, respectively (Table 1). The application of 100% NPK + FYM @ 5 t ha⁻¹ recorded significantly highest Exch-K (201.0 mg kg⁻¹) in 0-15 cm depth followed by 150% NPK (187.4 mg kg⁻¹). The Exch-K was highest in the treatment fertilized continuously with 100% NPK + FYM @ 5 t ha⁻¹, which can be attributed to effect of FYM on exchange site of soil and resulted in maximum accumulation of this fraction. Blake *et al.* (1999) reported that although, FYM is not a preferred source of K but due to increased cation exchange capacity (CEC) of the soil, increased organic surfaces helps in ion exchange, resulting in an increase in exchangeable and plant available K. Similarly, Bhattacharyya *et al.* (2006)

reported that higher amount of K is attributed to the process of structural K released through increasing the area of exchangeable surfaces, and due to the accelerated weathering of the interlayer K by application of FYM. The Exch-K decreased with increase in depths from 0-15 cm to 30-45 cm, except that 100% NP, N and control plots. The higher concentration of Exch-K under K fertilized plots in surface soil could be attributed to the addition of K through plant residues, manures and fertilizers (Sharma *et al.* 2009). Contrarily, the amount of Exch-K is relatively less in surface as compared to sub-surface soil in the plots those had not received K fertilizers (N, NP and control). The extent of decrease in Exch-K due to omission of K (100% NP) in comparison to 100% NPK was recorded to the tune of 41, 36 and 30 per cent in 0-15, 15-30 and 30-45 cm depths, respectively.

The NEK varied from 623 to 945, 641 to 944 and 658 to 942 mg kg⁻¹ in 0-15, 15-30 and 30-45 cm depths, respectively. Application of 100% NPK + FYM @ 5 t ha⁻¹ recorded significantly highest NEK (945 mg kg⁻¹) followed by 150% NPK (622.5 mg kg⁻¹). This form of K decreased with increase in the depths of soil in all treatments except that control, NP and N may be due to absence of K fertilizers in the sequence. Subba Rao and Sekhon (1990) reported that low value of NEK in surface soils may be due to the release of NEK to compensate for the loss of available K by crop plants and leaching loss. Srinivasarao *et al.* (2014) also reported that continuous cropping of pearl millet with no manures and fertilizers in an Alfisols resulted in increase in the NEK in the sub-surface as compared to surface soil depth (0-20 cm).

The lattice K ranged from 6445 to 17078, 6751 to 16752 and 7071 to 16193 mg kg⁻¹ in 0-15, 15-30 and 30-45 cm depths, respectively with a mean value of 6756 to 16674 mg kg⁻¹. The application of 100% NPK along with FYM @ 5 t ha⁻¹ resulted highest lattice K value (17078 mg kg⁻¹) followed by 150% NPK (16763 mg ka⁻¹) in 0-15 cm depth, the sub-surface depth also exhibited similar trend. The lattice K contributes about 93% of the total K, indicating the presence of fixed forms of K in the soil (Fig. 3). The increased contribution of this form to total K was maximum compared to other fractions might be due to a part of WSK and Exch-K was converted to NEK forms, besides their utilization by growing plants (Jat *et al.* 2014). Lattice K is generally assumed to be only slowly available to plants; however, the availability is dependent on the level of K in the other forms and the degree of weathering of feldspars and micas, constituting the mineral K fractions.

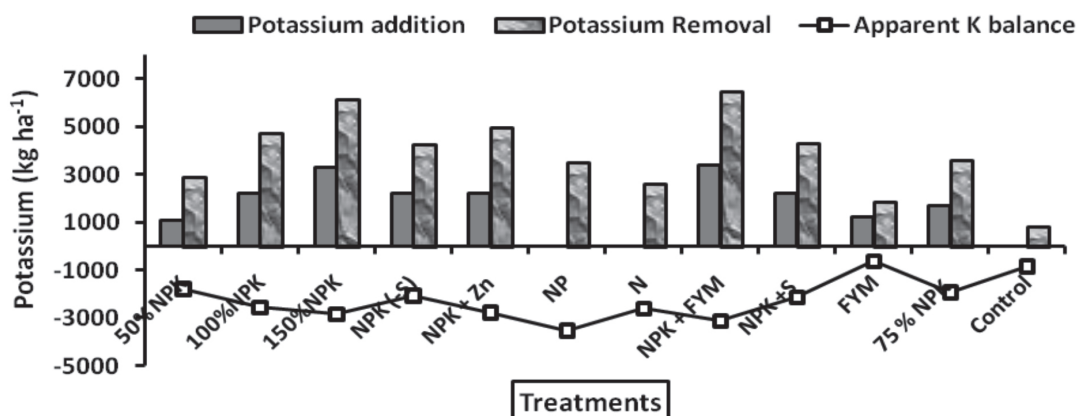


Fig. 1. Impact of long term manuring and fertilization on apparent K balance

The total K content varied between 7145 to 18233, 7470 to 17897 and 7811 to 17332 mg kg⁻¹ in 0-15 cm, 15-30 cm and 30-45 cm depths, respectively. Application of 100% NPK recorded significantly highest total K content at all the depths. The magnitude of response of various fertilizer treatments was observed in the order: 100% NPK + FYM > 150% NPK > 100% NPK + S > 100% NPK + Zn > 100% NPK > 75% NPK + 25% N through FYM > 100% NPK (S) > 50% NPK > FYM > 100% NP > 100% N and least in control. Imbalanced fertilization (100% NP or 100% N) resulted in depletion of total K. Similarly, application of FYM @ 10 t ha⁻¹ recorded relatively less amount of total K indicating FYM alone could not found beneficial in improving K regime of soil in long run. It was observed that application FYM alone could not fulfill the K nutrition of crop either in terms of yield or maintenance of K status of soil. Bhattacharya *et al.* (2008) reported depletion of total soil K in the top soil after 30 years of cropping, with the highest depletion of K recorded in the 0-15 cm soil layer was under the NP treatment followed by N + FYM treated plots, respectively.

Apparent potassium balance

The results pertaining to apparent K balance under sorghum-wheat sequence in Vertisols revealed that, the highest negative balance of K was recorded with the application of 100% NP (-3513 kg ha⁻¹) followed by 100% NPK + FYM @ 5 t ha⁻¹ (-3110 kg ha⁻¹) and 150% NPK (-2838 kg ha⁻¹) (Fig. 1). Similarly, other treatments also exhibited negative K balance. The probable reasons for this is primarily due to the fact that K application seldom matches K removal, resulting in greater dependence on soil K. Under such conditions there is greater demand on soil reserve K to meet the crop K requirement as the total

uptake of K by the crops far exceeded the amount of K applied. Application of 100% NP and 100% N alone also recorded highest negative balance to an extent of 3513 and 2604 kg ha⁻¹, respectively. This is obvious due to continuous absence of K fertilization in the crop sequence. In rice-wheat, Singh *et al.* (2014) and in rice-rice and soybean-wheat sequence, Rupa *et al.* (2003) clearly demonstrated mining of soil K with the application of NP and even with NPK application, respectively.

Changes in status of available K

The data pertaining to changes in the status of available K over initial (358 kg ha⁻¹) is depicted in fig. 2. An improvement in the available K status was observed under NPK + FYM (470 kg ha⁻¹), 150% NPK (432 kg ha⁻¹) and 100% NPK (378 kg ha⁻¹) whereas, imbalanced fertilization NP (225 kg ha⁻¹) or N (219 kg ha⁻¹) treated plots, showed a decline in the status of available K. The increase in available K in NPK+ FYM was due to larger amount of SOC which adds additional amount of K and also provide sorption site for K on application of organic manure along with mineral fertilizer (Singh *et al.* 2014). The decline in available K was noted in control, FYM, 100% N and 100% NP treatments may be due to inadequate supply or complete absence of K through these treatments in the sequence.

Contribution of different forms of K to total K

The contribution of different forms of K to total K (Fig. 3) showed that the lattice K contributing highest (92%) to total K followed by NEK (6%), available K (1.09%), Exch-K (1.04%) and WSK (0.05%) indicating the dominance of fixed forms of K in the soil. Pasricha (2002) reported that major portion of soil K exists as part of mineral structure

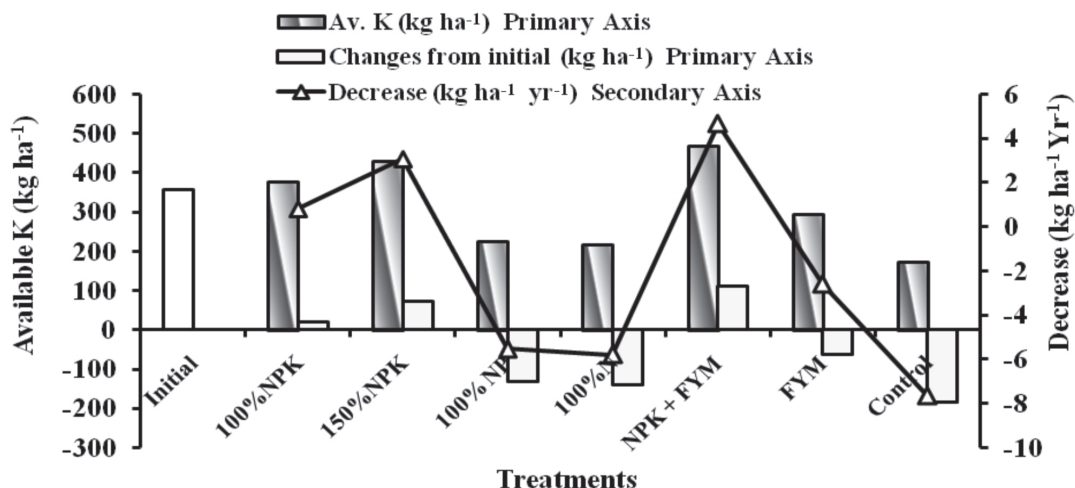


Fig. 2. Impact of long term manuring and fertilization on change in status of available K

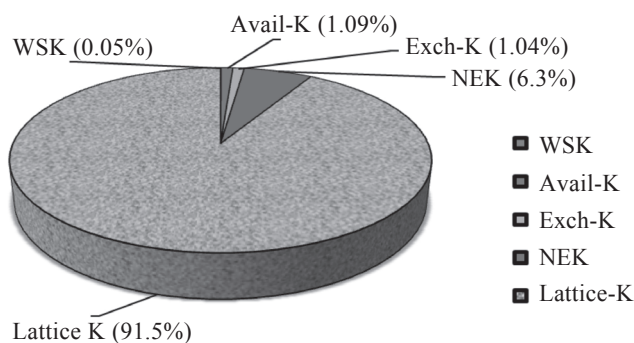


Fig. 3. Contribution of different forms of K to total K

and in a fixed or NEK form with a small fraction as WSK and Exch-K in soil. The sequential order of dominance of different forms of K in this study was in the order: lattice K > NEK > Exch-K > available > WSK. The highest value of K fractions was recorded in the treatments 150% NPK and 100% NPK + FYM. Similar trend of relative contribution of different forms of K to total K were observed by Jatav *et al.* (2010).

Yield and total uptake

The grain yield of sorghum and wheat (Table 2) was influenced significantly with the application of NPK + FYM (5.27 and 3.39 t ha⁻¹) followed by 150% NPK (4.87 and 3.21 t ha⁻¹). Although these treatments found equally beneficial in increasing grain yield of sorghum and wheat, balanced fertilization along with FYM can be preferred over 150% NPK. The FYM played an important role in supplying all nutrients including micronutrients while improving the physical and biological condition of soil. Similar beneficial effects of FYM along with NPK have been reported

Table 2. Effect of different treatments on yield and total uptake of K by sorghum and wheat

Treatments	Grain yield (t ha ⁻¹)		Total uptake (kg ha ⁻¹)	
	Sorghum	Wheat	Sorghum	Wheat
50% NPK	2.68	1.88	71.0	43.8
100% NPK	3.70	2.79	106.6	64.3
150% NPK	4.87	3.21	149.4	88.3
100% NPK (-S)	3.43	2.44	88.2	58.5
100% NPK + Zn	4.17	2.93	124.2	68.1
100% NP	3.00	1.43	75.2	37.4
100% N	1.88	0.89	45.2	21.7
100% NPK + FYM	5.27	3.39	167.9	99.0
100% NPK + S	4.32	3.01	131.2	73.2
FYM	2.50	1.18	60.4	28.7
75% NPK + 25% N through FYM	3.36	1.98	88.6	50.3
Control	0.33	0.05	4.2	1.5
CD (<i>P</i> = 0.05)	0.58	0.20	15.4	4.9

by Sawarkar *et al.* (2013) and Singh *et al.* (2014). They observed that the continuous use of chemical fertilizers applied either singly or in combination with FYM had a marked effect on grain yields under rice-wheat and soybean-wheat sequence in Mollisol and Vertisol, respectively. Similarly, the improvement in physical and biological properties as a result of application of FYM provide desirable condition for both plant growth and nutrient uptake, which might be the reason to sustain productivity of the crop (Ingle *et al.* 2014). Application of 50% NPK declined the grain yield of sorghum and wheat to the extent of 28 and 33 per cent as compared to 100% NPK. Yaduwanshi *et al.* (2013) showed that yield of rice and wheat grown on a reclaimed sodic soil after 12 years could be sustained with 50% NPK with GM or

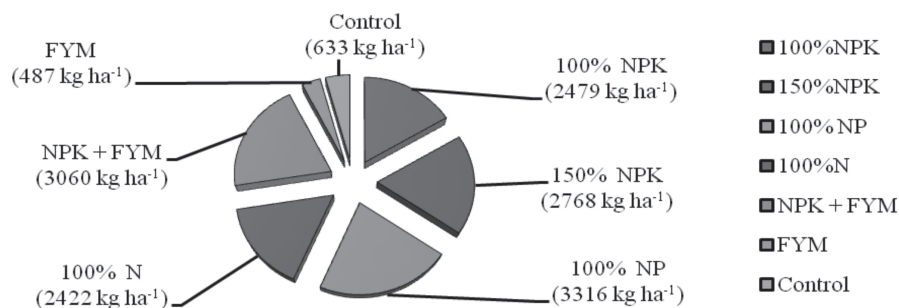


Fig. 4. Contribution of non-exchangeable K (kg ha⁻¹) to total uptake

FYM. It is associated with the beneficial effect of GM or FYM due to steady supply of all nutrients including the micronutrients and improvement in soil physical conditions. In the present study, application of FYM along with 100% NPK was found beneficial in sustaining the yield of sorghum and wheat.

The trend in K uptake was almost similar as grain yield of sorghum and wheat, the highest uptake was noted to the extent of 168 and 99 kg ha⁻¹ by sorghum and wheat, respectively with the application of NPK + FYM followed by 150% NPK. The 12 per cent reduction in the total K uptake was recorded due to 150% NPK in comparison to 100% NPK + FYM.

Contribution of non-exchangeable K to total uptake

The contribution of NEK (kg ha⁻¹) to total uptake and per cent contribution of NEK to total uptake (Fig. 4 and 5) showed that the contribution of NEK (kg ha⁻¹) to total uptake was higher in NP (3316 kg ha⁻¹), NPK + FYM (3060 kg ha⁻¹), 150% NPK (2768 kg ha⁻¹), 100% NPK (2479 kg ha⁻¹) and N (2422 kg ha⁻¹) alone treated plots with per cent contribution corresponding to 96, 48, 46, 53 and 95, respectively. The results indicated that fertilizer K application considerably reduced the contribution of NEK to total uptake. The probable reason for reduced contribution of NEK to total uptake under NPK, NPK + FYM

treated plots may be due external supply of K *i.e.* 2200 and 3375 kg ha⁻¹, respectively as compared to N and NP treated plots. Reduced contribution of NEK to total uptake were also reported by Santhi *et al.* (1998) in finger millet-maize-cowpea sequence on Vertic Inceptisol and Rupa *et al.* (2003) in soybean-wheat-cowpea sequence on Vertisols.

Effect of available K on yield

The impact of available K on yield was assessed by plotting sustainable yield index (SYI) as dependant variable and soil available K as independent variable (Rupa *et al.* 2003) (Fig.6). The R² value for sorghum and wheat was noted almost similar (0.790 and 0.766) indicating need of fertilizer K in the nutrition of both sorghum and wheat. The application of NP and N alone to the sequence exhibited drastic reduction in sustainable yield index for sorghum (0.245 and 0.168) and wheat (0.235 and 0.173), whereas inclusion of fertilizer K in the sequence recorded substantial improvement in sustainable yield index, further it was improved with the application of NPK + FYM indicating need of K in maintaining the sustainability of the system. It was also noticed that continuous cropping without manures and fertilizers showed a decline in SYI (-0.008 and 0.004). Rupa *et al.* (2003) reported that better sustainability of the system could

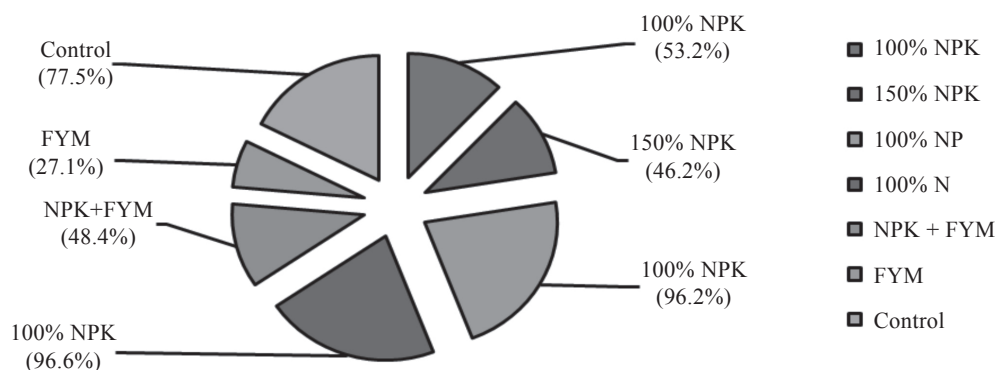


Fig. 5. Per cent contribution of non exchangeable K to total uptake

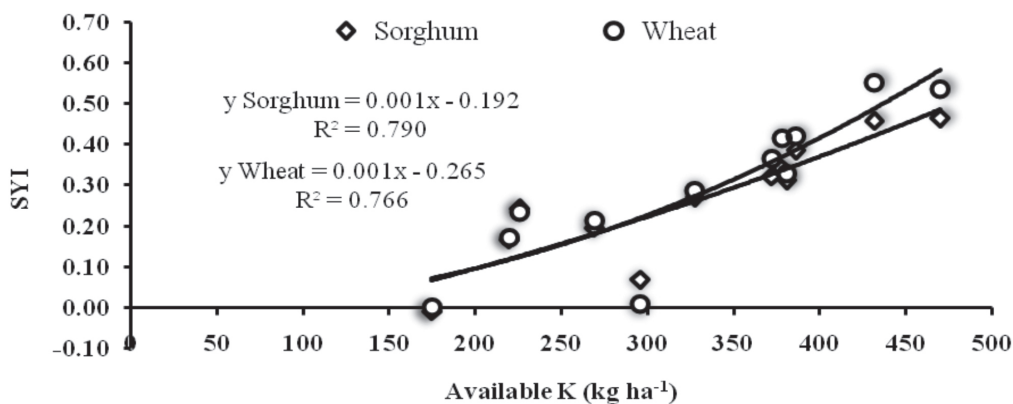


Fig. 6. Relationship among sustainable yield index (SYI) and available K

Table 3. Simple correlations among different fractions of K, yield and total K uptake

K fractions	Correlation coefficient			
	Sorghum	Wheat	Total K uptake	
			Sorghum	Wheat
Available K	0.891**	0.905**	0.913**	0.941**
Water soluble K	0.845**	0.850**	0.846**	0.885**
Exchangeable K	0.889**	0.903**	0.912**	0.939**
Non-exchangeable K	0.852**	0.859**	0.859**	0.903**
Lattice K	0.791**	0.844**	0.805**	0.846**
Total K	0.799**	0.852**	0.814**	0.855**

The data (Table 4) revealed that available K was significantly correlated with WSK ($r = 0.906^{**}$), Exch-K ($r = 0.989^{**}$), NEK ($r = 0.949^{**}$), lattice K ($r = 0.870^{**}$) and total K ($r = 0.881^{**}$) indicating dynamic equilibrium among all the form of K. Intense weathering of primary and secondary K-minerals such as micas, feldspar and micaceous minerals of the clay fractions seems to maintain dynamic equilibrium among various forms of K. The significant correlation among yield and various forms of K also reported by Sawarkar *et al.* (2013).

Table 4. Simple correlations among different fractions of K

K fractions	Available K	Water soluble K	Exchangeable	Non-exchangeable	Lattice K	Total K
Available K	1.00					
Water soluble K	0.906**	1.00				
Exchangeable K	0.989**	0.899**	1.00			
Non-exchangeable K	0.949**	0.943**	0.946**	1.00		
Lattice K	0.870**	0.969**	0.863**	0.881**	1.00	
Total K	0.881**	0.974**	0.874**	0.892**	0.991**	1.00

be achieved through inclusion of K in the fertilizer schedule.

Correlations among K forms, yield and uptake

The simple correlations among K fractions and grain yield as well as uptake by sorghum and wheat is presented in table 3. The grain yield of sorghum and wheat was significantly correlated with all forms of K, however, available K exhibited highest correlation coefficient with sorghum ($r = 0.891^{**}$) and wheat ($r = 0.905^{**}$) followed by Exch-K, indicating these forms of K have immediate beneficial influence on yield of crop rather than those fixed on exchange sites of clays.

Conclusions

The results of the present study indicate that, continuous application of NPK + FYM over a period of 24 years to sorghum-wheat sequence improved the status of available K as well as K fractions in soil over control, NP and N alone treated plots. The contribution of different fractions of K to total K indicated substantial contribution of lattice K followed by non-exchangeable K, available K, exchangeable K and water soluble K. Continuous cropping without manures and fertilizers (control), imbalanced fertilization devoid of K (NP and N) and even though NPK+FYM resulted negative K balance due to cultivation of sorghum-wheat sequence for over 24

years. The productivity of the system sustained with the application of NPK + FYM. Fertilizer K application considerably reduced the contribution of non-exchangeable K to total K uptake, indicating significance of applied K in the nutrition of crops. The SYI of the system improved with the application of NPK + FYM, whereas omission of K from fertilizer schedule resulted in deterioration of soil quality thereby causing decline in SYI. All the K fractions exhibited significant and positive correlation with yield and uptake. Significant and positive correlation among various fractions of K indicating dynamic equilibrium in soil.

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