Effect of Long-term Application of Organic, Inorganic and Integrated Nutrients on Soil Potassium Fractions in a Vertisol of Central India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The present study was conducted at the experimental field of College of Agriculture, Indore during 2018-2019.Soybean (cv. JS-9305), was grown with 80 kg ha^{-1} seed rate with row to row and plant to plant spacing of 40 cm X 5 cm. Soybean crop was grown as per standard cultural practices. The experiment was conducted with nine treatments viz., T1- unfertilized control, T2- 20 kg N + 13 kg P ha^{-1}, T3- 30 kg N + 20 kg P ha^{-1}, T4- 40 kg N + 26 kg P ha^{-1}, T5- 60 kg N + 35 kg P ha^{-1}, T6- 6 t ha^{-1} FYM + 20 kg N + 13 kg P, T7- 5 t ha^{-1} crop residues + 20 kg N + 13 kg P, T8- 6 t ha^{-1} FYM and T9- 5 t ha^{-1} crop residues (CR) laid out in a randomized block design (RBD) having three replications. Different K fractions in soil sample viz., water soluble-K, available-K, exchangeable-K, non-exchangeable-K, lattice-K and total-K were determined following standard methods. The mean values were grouped for comparisons and the least significant differences among them were calculated at $p < 0.05$ confidence level using ANOVA statistics. The results of present study revealed

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that to sustain K status in Vertisol there is a need of K application along with organic manure/crop residue. The application of organics with and without N and P application can sustain the Lattice-K availability in long run under soybean based cropping system of Vertisols. The rate of chemical fertilizer can be reduced up to 50% due to long term application of 6 t ha^{-1} FYM or 5 t ha^{-1} crop residues are added to soil.

1. INTRODUCTION

"Potassium is the one of the three major nutrients (NPK) essential to plants. The consumption of potassium fertilizer in India increased from 0.24 million tonnes (mt) to 3.5 mt in last 50 years. However, it has dropped ratio from 5:2.4:1.0 to 8.36: 2.76:1.0. Currently we are importing 100% of the requirement of K due to widening the nutrient imbalance, resulting in a huge burden to the exchequer and a subsidy burden of thousands crores of rupees to the Government of India" [1]. "Long-term intensive cropping, in the absence of K inputs, adversely affected the K supply to crop plants and consequently crop yields" [2]. "Potassium is an essential element for plant growth which exists in soil in four forms, viz., water soluble-K, which is taken up directly by plant; exchangeable-K, held by negative charges on clay particles and is available to plant; fixed-K which is trapped between layers of expanding lattice clays; and lattice-K and integral part of primary K bearing minerals" [3]. "The knowledge about different forms and availability of potassium is must while, studying the response of crops to potassium application. As Potassium supply to crop plants is a complex phenomenon involving relationships among various K fractions in soils. Potassium availability to plants in general is governed by different forms of K viz., water soluble-K, exchangeable-K, fixed-K and mineral-K" [4].

"Plants utilize not only the readily available K but also the non- exchangeable and mineral K during the crop growth. The potassium availability to plants is determined by the rate of change in the dynamic equilibrium between different forms of K in the soil which in turn is controlled by the type of mineral, rate of weathering and exchange properties of the soil" [5]. "Potassium is essential for various metabolic activities of living cell, transformation of carbohydrates, reduction of nitrates, synthesis of protein and normal meristematic activities where it acts as a catalyst or as a co-factor in enzymatic reaction of living cells. It has been suggested that potassium may also affect photosynthesis, maintenance of turgor in plant cells as well as formation of oil and imparting disease resistance. The black soils, through rich in available potassium have generally poor reserves of non exchangeable potassium" [6]. Although most of the Indian soils have been reported to be rich in Potassium [7,8] but due to cultivation of high yields varieties of crops with optimum applications of high rates of N and P tend to deplete the K reserve of soil at faster rate [5]. "To formulate sound fertilizers recommendation, potassium supplying capacity of soil is essential" [9]. "This will depend not only on the available K content of soil, but a sound knowledge of different forms of K and their relationship among themselves is also required. Long-term experiments provide a means of evaluating sustainable management systems in agriculture" [10].

"Potassium deficiencies are now more widespread even on heavy textured soils such as alluvial illitic soils in India. Several studies have shown substantial contribution of non-exchangeable K towards K nutrition of crops grown on illite dominant alluvial soils" [11]. "This is particularly so when cropping continues with N + P application without K addition. Potassium supply to crop plants is a complex phenomenon involving relationships among its various chemical forms. The dynamic equilibrium among the forms directs the release of K from non-exchangeable form to available forms under K stress environment. As the growing season is limited in case of short duration high yielding varieties, the rate of K supply during crop growth assumes significance" [12]. Therefore, current interest in K fertility soils has switched from simple measurement of the amounts of exchangeable K to determination of rate of K supply from soil during crop growth. Keeping these facts in view present study was under taken to study the effect of long term application of organic inorganic and integrated nutrient management on soil potassium fractions in vertisol of central India.

2. MATERIALS AND METHODS

2.1 Experimental Site and Climate

The present study was conducted at the experimental field of College of Agriculture, Indore during 2018-2019. The area has almost uniform topography with light to medium black soils. Indore is situated in Malwa Plateau in westernparts of Madhya Pradesh on 22.43°N latitude and 75.66°E longitudes with analtitude of 555.5 meters above the mean sea level. The soils of the area are medium deep, deep and shallow deep black soils, mostly derived from Deccan trap. They are called black cotton soils and classified as *Vertisols.* The textural class was clay loam having high clay content (40-60%) mainly of smectite group.

The site is situated in semi-arid (Hot moist) climatic zone of Malwa Plateau in central Indian state Madhya Pradesh. The summers are dry with the rising temperature up to 44°C or even higher during April-May. The winters are normal with temperature descending up to 10°C or even less during December and January. The average annual rainfall 750 mm to 1000 mm and 90 percent of which is received during the last week of June, July, August, September and first week of October through South west monsoon. The mean annual value of potential evaporation (PE) and rainfall are1781.52 mm and 919.30 mm, respectively.

2.2 Experiment Details

The on-going research project initiated in 1983 on "All India Coordinated Research Project on Dryland Agriculture" was used for this investigation. Soybean (cv. JS-9305), was grown with 80 kg ha^{-1} seed rate with row to row and plant to plant spacing of 40 cm×5 cm. Soybean crop was grown as per standard cultural practices. The experiment was conducted with nine treatments viz., T1- unfertilized control, T2- 20 kg N + 13 kg P ha^{-1}, T3- 30 kg N + 20 kg P ha^{-1}, T4- 40 kg N + 26 kg P ha^{-1}, T5- 60 kg N + 35 kg P ha^{-1}, T6- 6 t ha^{-1} FYM + 20 kg N + 13 kg P, T7- 5 t ha^{-1} crop residues + 20 kg N + 13 kg P, T8- 6 tha^{-1} FYM and T9- 5 tha^{-1} crop residues (CR) laid out in a randomized block design (RBD) having three replications. The application of nutrient was as per the designed treatments.

2.3 Experimental Soil

The physico-chemical properties experimental soil was analyzed as per the method described in Singh et al. [13]. The soil of experimental site is classified as Vertisol (*Typic Haplusterts*) with smectite as the dominant clay mineral. Vertisols are churning heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks during summer season. The soil of the experimental site is clayey in texture with 9.28, 30.12 and 60.02 per cent of sand, silt and clay, respectively. The soil was low in soil organic carbon (0.28%), medium in available N (184.2 kg ha^{-1}), medium in available P (8.18 kg ha^{-1}) and high in available K (489.1 kg ha^{-1}). The soil was normal in reaction (pH 7.65) and electrical conductivity (EC) was 0.54 dS m^{-1}.

2.4 Soil Sampling, Processing and Determination of Soil K-fractions

"Soil samples were collected from 0-10 cm and 10-20 cm depth after harvest of *kharif* season soybean crop from 26 years old ongoing experiments; and were homogenized. Visible litter and roots were picked out from collected soil samples. The soil samples were air-dried at room temperature, ground and sieved through 2 mm sieve. The processed soil was stored in air tight plastic containers for further analysis of different K fractions. Different K fractions in soil sample viz., water soluble-K, available-K, exchangeable-K, non exchangeable-K, lattice-K and total-K were determined following standard methods. The water-soluble K was determined in 1:2.5 soil : water extract by shaking soil-water suspension for half an hour" [14]. "The soil available K was extracted from the soil using neutral normal ammonium acetate in 1:5 soil solution ratio and the K in extract was recorded using flame photometer" [15]. "The soil Exchangeable-K fraction was calculated as the difference between available K and water soluble K. The total- K content was determined by digesting the soil samples with hydrofluoric acid (HF) in a closed vessel" [16]. The lattice-K was also calculated from total K.

2.5 Statistical Analysis

The experiment comprised with nine treatments laid out in a randomized block design (RBD) with three replications under soybean crop. All the measurements are the mean value of three separate replicates. Data was subjected to an analysis of variance. The mean values were grouped for comparisons and the least significant differences among them were calculated at $p < 0.05$ confidence level using ANNOVA statistics as outlined by Gomez and Gomez [17].

3. RESULTS

3.1 Available-K

The available-K as influenced by various treatments has been determined at two depths i.e. 0-10 cm and 10-20 cm soil depth and data are presented in Table 1. The available-K at surface layer (0-10 cm) ranged from 381.01-593.78 kg ha^{-1} (Fig. 1) among various treatments and it ranged from 312.5-474.3 kg ha^{-1} in the lower depth i.e. 10-20 cm (Fig. 2). The available-K content was affected significantly due to different treatments. The lowest available-K at 0-10 cm depth of soil was obtained in T1 (control). The highest value 593.78 kg ha^{-1} was noticed in the treatment T6 (Fig.1). However, the available-K content declined with the depth but the trend of

available-K was also maintained at 10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. The overall results suggested that available-K content was in medium category in case of control treatment while, it was high in rest of the treatment under study. The results revealed that, the available-K has changed from high to medium category in case of the treatment T1 where no chemical fertilizer was applied while in other treatments it was in high category. In the surface layer, the available-K content was 28.53-55.84 percent higher in case of the treatment where organics were applied with and without chemical fertilizer as compared to control. The result suggests that by addition of organics, use of chemical fertilizer may be reduced without affecting the status of available-K in long term in vertisols.

Table 1. Effect of various treatments on soil available-K and water soluble-K

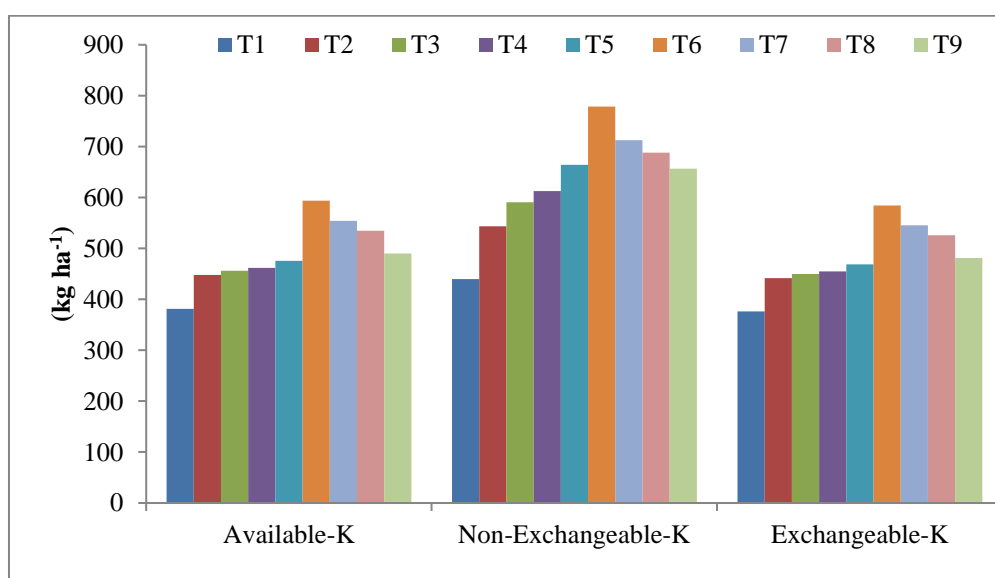| Treatment	Available K (kg ha^{-1})		Water soluble K (kg ha^{-1})	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
T1: Control	381.01	312.52	4.94	1.22
T2: 20 kg N + 13 kg P ha^{-1}	447.69	410.51	5.91	3.83
T3: 30 kg N + 20 kg P ha^{-1}	455.99	420.53	6.45	4.22
T4: 40 kg N + 26 kg P ha^{-1}	462.08	433.23	7.23	4.81
T5: 60 kg N + 35 kg P ha^{-1}	475.91	448.54	7.32	4.96
T6: 6 t ha^{-1}FYM + 20 kg N + 13 kg P	593.78	474.32	9.61	6.88
T7: 5 t ha^{-1}crop residues + 20 kg N + 13 kgP	554.22	459.61	8.76	6.52
T8: 6 t ha^{-1} FYM	534.85	430.11	8.72	6.56
T9: 5 t ha^{-1}crop residues	489.75	460.22	8.66	6.64
SEm(±)	54.13	11.78	1.07	0.88
CD (p=0.05)	114.7	24.98	2.28	1.86

Fig. 1. Effect of different nutrient management on soil available K, Non-exchangeable K and exchangeable K (0-10 cm)

3.2 Water Soluble-K

The water soluble-K as influenced by different treatments at two depths i.e. 0-10 cm and 10-20 cm are presented in Table 1. The water soluble-K at surface layer (0-10cm) ranged from 4.94-9.60 kg ha^{-1} among various treatments and it ranged from 1.22-6.88 kg ha^{-1}in the lower depth i.e. 10-20 cm (Fig. 3). The water soluble-K content was influenced significantly due to different treatments. The highest value 9.60 kg ha^{-1} was noticed in the treatment T6, while the lowest value observed in control (4.94 kg ha^{-1}) followed by T2 (5.90 kg ha^{-1}). However, the water soluble-K content declined with the depth but the trend of water soluble-K was also maintained at 10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. The overall results suggest that water soluble K lower in the treatment where no fertilizer was applied or sub-optimal doses of N and P were applied as compared to the treatment where super optimal doses of fertilizer were applied or organics applied with or without chemical fertilizer.

3.3 Exchangeable-K

The data pertaining to the soil exchangeable-K as influenced by different treatments has been determined at two depths i.e. 0-10 cm and 10-20 cm soil depth and data are presented in Table 2. The exchangeable-K at surface layer (0-10 cm) ranged from 376.07-584.18 kg ha^{-1} (Fig. 1) among various treatments and it ranged from 312.5-490.5 kg ha^{-1} (Fig. 2) in the lower depth i.e. 10-20 cm. The exchangeable-K content was affected significantly due to different treatments. The highest value 584.18 kg ha^{-1} was noticed in the treatment T6, while the lowest value observed in control (376.07 kg ha^{-1}) followed. However, the exchangeable-K content declined with the depth but the trend of exchangeable-K was also maintained at 10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. The overall results suggest that exchangeable-K content was lowest in case of control treatment and increased as the level of N and P application increased up to 150% RDF. The results clearly emphasized that by the application of organics with and without K application can sustain the Exchangeable-Kin long run under soybean based cropping system of Vertisols, while reducing the use of chemical fertilizer.

3.4 Non-Exchangeable-K

The non-exchangeable-K as influenced by different treatments has been determined at two depths i.e. 0-10 cm and 10-20 cm soil depth and data are presented in Table 2. The non-exchangeable-K at surface layer (0-10 cm) ranged from 439.89-778.9 kg ha^{-1} (Fig 1) among various treatments and it ranged from 388.6-610.7 kg ha^{-1} in the lower depth i.e. 10-20 cm (Fig. 2). The non exchangeable-K content was influenced significantly due to different treatments. The highest value 778.9 kg ha^{-1}was noticed in the treatment T6 while, the lowest value observed in control (439.89 kg ha^{-1}). However, the Non-exchangeable-K content declined with the depth but the trend of non-exchangeable-K was also maintained at 10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. The overall results suggest that non-exchangeable-K content was in lowest in case of control treatment and it increased as the level of N and P application was increased up to 150% of RDF. The application of organics with and without fertilizer application can also sustain the non-exchangeable-K in long run under soybean based cropping system of Vertisols.

The lattice-K data at two depths i.e. 0-10 cm and 10-20 cm soil depth are presented in Table 3. The lattice-K at surface layer (0-10 cm) ranged from 7177.1-13154.3 kg ha^{-1} (Fig. 4) among various treatments and it ranged from 7144.5-12994.4 kg ha^{-1} (Fig. 5) in the lower depth i.e. 10-20 cm.

The lattice-K content was affected significantly due to different treatments. The highest value13154.3 kg ha^{-1} was noticed in the treatment T6, while the lowest value observed in control (7177.1kg ha^{-1}). However, the lattice-K content declined with the depth but the trend of lattice-K was also maintained at 10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. The overall results suggest that lattice-K content was in lowest in case of control treatment and increased in other treatments having higher dose of N and P fertilizer and due to addition of organics high in all the other treatments. The results clearly emphasized that by the application of organics with and without K application can sustain the lattice-K availability in long run under soybean based cropping system of Vertisols.

3.5 Total-K

The total-K as influenced different treatments has been determined at two depths i.e. 0-10 cm and 10-20 cm and data are presented in Table 3. The total-K at surface layer (0-10 cm) ranged from 7998.3-14527.3 kg ha^{-1} among various treatments and it ranged from 8102.4-14888.4 kg
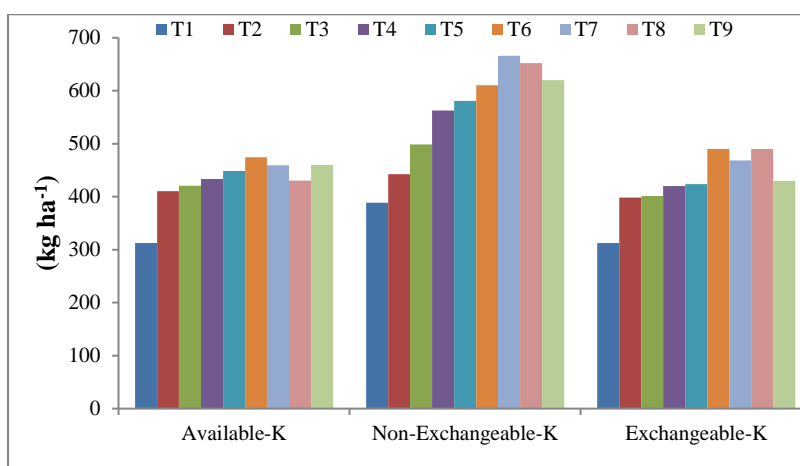
Fig. 2. Effect of different nutrient management on soil available K, Non-exchangeable K and exchangeable K (10-20 cm)

Table 2.Effect of various treatments on soil exchangeable-K and non exchangeable-K

| Treatment	Exchangeable-K (kg ha⁻¹)		Non-Exchangeable K (kg ha⁻¹)	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
T1: Control	376.07	312.54	439.89	388.62
T2: 20 kg N + 13 kg P ha⁻¹	441.79	398.42	543.21	442.54
T3: 30 kg N + 20 kg P ha⁻¹	449.54	401.53	590.51	498.93
T4: 40 kg N + 26 kg P ha⁻¹	454.85	420.31	612.89	562.82
T5: 60 kg N + 35 kg P ha⁻¹	468.61	423.91	664.23	580.71
T6: 6 t ha⁻¹FYM + 20 kg N + 13 kg P	584.18	490.52	778.92	610.72
T7: 5 t ha⁻¹crop residues + 20 kg N + 13 kgP	545.46	468.54	712.63	665.84
T8: 6 t ha⁻¹ FYM	526.15	490.23	688.36	652.23
T9: 5 t ha⁻¹crop residues	481.09	429.52	656.34	620.21
SEm(±)	54.98	30.94	54.61	15.22
CD (p=0.05)	116.57	65.64	115.78	32.91
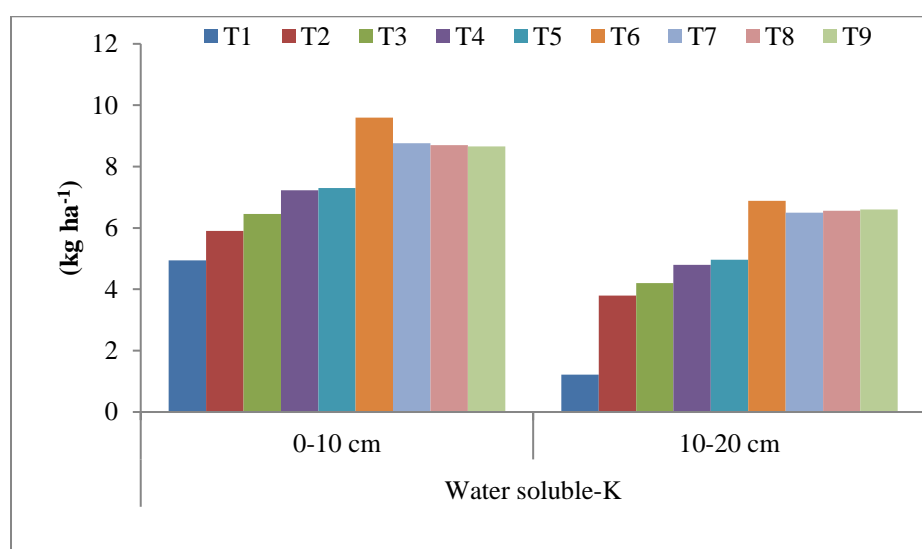
Fig. 3. Effect of different nutrient management on soil water soluble K Lattice-K
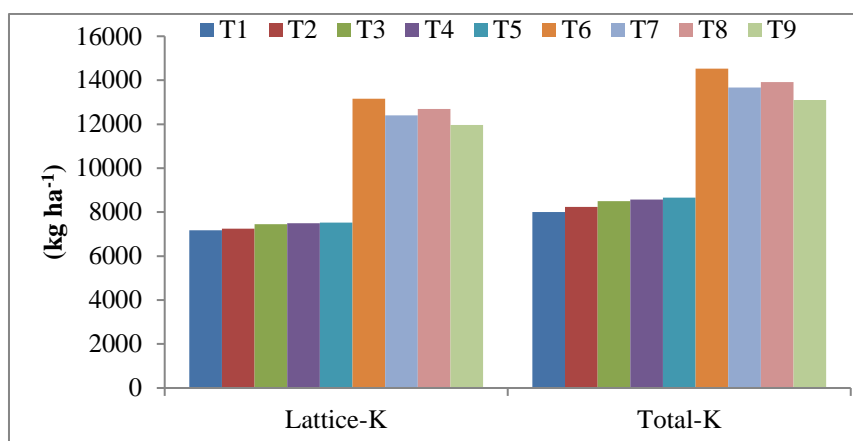
Fig. 4. Effect of different nutrient management on soil lattice K and total K (0-10 cm)

Table 3.Effect of various treatments on soil lattice-K and total-K

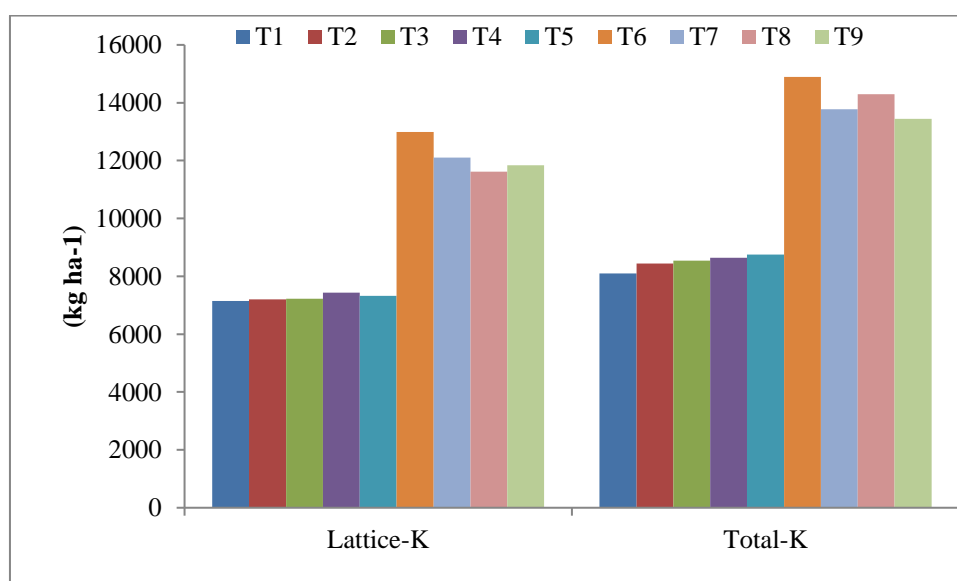| Treatment	Lattice K(kg ha^{-1})		Total K (kg ha^{-1})	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
T1: Control	7177.1	7144.5	7998.3	8102.4
T2: 20 kg N + 13 kg P ha^{-1}	7246.1	7200.1	8237.2	8443.2
T3: 30 kg N + 20 kg P ha^{-1}	7446.5	7222.9	8493.4	8540.3
T4: 40 kg N + 26 kg P ha^{-1}	7492.0	7435.1	8567.1	8640.7
T5: 60 kg N + 35 kg P ha^{-1}	7520.9	7329.8	8661.2	8751.4
T6: 6 t ha^{-1}FYM + 20 kg N + 13 kg P	13154.3	12994.4	14527.3	14888.4
T7: 5 t ha^{-1}crop residues + 20 kg N + 13 kgP	12402.2	12101.5	13669.2	13770.3
T8: 6 t ha^{-1} FYM	12694.8	11620.5	13918.1	14290.4
T9: 5 t ha^{-1}crop residues	11959.9	11840.9	13106.4	13442.1
SEm(±)	2610.1	2613.2	2720.4	2847.6
CD (p=0.05)	5533.5	5539.9	5767.2	6036.9

Fig. 5. Effect of different nutrient management on soil lattice K and total K (10-20 cm)

ha^{-1} in the lower depth i.e. 10-20 cm. The total -K content was affected significantly due to different treatments. The highest value 14527.3 and 14888 kg ha^{-1} was noticed in the treatment T5, while the lowest value observed in control. However, the total-K content increased with the depth but the trend of total-K was also maintained at 10-20 cm depth as it was in surface layer i.e.0-10 cm depth. The overall results suggest that total-K content was influenced by the sub-optimal, optimal, super-optimal and the addition of organics with or without application of fertilizer those treatments recorded higher total-K in both the depth as compared to control treatment. It may be concluded by the results obtained that by the use of organics (FYM / Crop Residues) one can reduce the application of N and P up to 50% of RDF without affecting the status of total-K under the fertility experiments of Vertisols.

4. DISCUSSION

The available-K comprises of exchangeable and water soluble. Insome instances, K may be available from fixed state to a substantial degree [18]. The available-K was more in surface layer than sub surface layer. Yaduvanshi et al. [19] reported that available-K increased in treatments receiving green manure or FYM with 120:26:42 kg ha^{-1} NPK. Das et al. [20] also reported that "addition of inorganic fertilizer 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 in highest content of soil available-K". The water soluble-K or soil solution-K is the form of potassium that is directly taken by the plants and microbes and also is the form subject to most leaching in soil. The water soluble-K was lower in the treatment where no fertilizer was applied or sub-optimal doses of N and P were applied as compared to the treatment where super optimal doses of fertilizer were applied or organics applied with or without chemical fertilizer. This was might be due to greater release of K from these treatments. These findings are in accordance with Yaduwanshi and Swaroop [21]. Such increased status of available and water soluble-K with the application of organics (FYM / crop residue) may be due to stimulating effect of FYM in reducing K fixation, thereby, bringing more potassium in the solution. The present findings are corroborated with the findings of Singh et al. [22], Singh et al. [23], Das et al. [9] and Dotaniya et al. [4].

The 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 exchangeable-K content declined with the depth but the trend of exchangeable-K was also maintained at10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. The higher exchangeable-K content in organics added treatments may be due to increased cation exchange capacity of soil due to continuous application of organics in these treatments. Increased organic surfaces helps in ion exchange, resulting in an increase in exchangeable and plant available-K. Similarly, Bhattacharya et al. [24] reported that "higher amount of K is attributed to the process of structural K released through increasing the area of exchangeable surface and due to the accelerated weathering of the interlayer K by application of FYM". "The higher concentration of Exchangeable-K under N and P fertilized plots as compared to control treatment could be attributed to the addition of K through plant residues" [25]. Similarly, the non exchangeable-K was also found declined with the depth but the trend of non exchangeable-K was also maintained at 10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. Similar results were also reported by Srinivas Rao et al. [26] and Jadhao et al. [18].

The lattice-K content was found declined with the depth but the trend was maintained at 10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. However, the total-K content increased with the depth but the trend of total-K was also maintained at 10-20 cm depth as it was in surface layer i.e. 0-10 cm depth. Bhattacharya et al. [27] reported depletion of total-K in the topsoil after 30 years of cropping, with the highest depletion of K recorded in o-15 cm soil layer was under control treatment followed by N+FYM and minimum in case of 100% NPK + FYM. Similar results were also reported by Srinivas Rao et al. [28], Kori et al. [29], Balik et al. (2019), Das et al. [20], Das et al. [9], Dotaniya et al. [4] and Shirale et al. [5].

5. CONCLUSION

Although most of the Indian soils have been reported to be rich in Potassium but due to cultivation of high yields varieties of crops with optimum applications of high rates of N and P tend to deplete the K reserve of soil at faster rate. The potassium supplying capacity of soil is not only depends on the available K content of

soil, but a sound knowledge of different forms of K is also required. The optimum applications or high rates of N and P tend to deplete the K reserve of soil at faster rate. This is study clearly concludes that to sustain K status in Vertisols there is a need of K application along with organic manure/crop residue. The application of organics with and without N and P application can sustain the Lattice-K availability in long run under soybean based cropping system of Vertisols. The rate of chemical fertilizer can be reduced up to 50% due to long term application of 6 t ha^{-1} FYM or 5 t ha^{-1} crop residues are added to soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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