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Potassium fixation and release in vertisol under organic, inorganic and integrated nutrient management in central India

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Abstract
The potassium fixation and release was studied under nine long term fertilizer treatments *viz.*,T_1- unfertilized control, T_2- 20 kg N + 13 kg P ha^{-1}, T_3- 30 kg N + 20 kg P ha^{-1}, T_4- 40 kg N + 26 kg P ha^{-1}, T_5- 60 kg N + 35 kg P ha^{-1}, T_6- 6 t ha^{-1} FYM + 20 kg N + 13 kg P, T_7- 5 t ha^{-1} crop residues + 20 kg N + 13 kg P, T_8- 6 t ha^{-1} FYM and T_9- 5 t ha^{-1} crop residues (CR). The K fixing capacity of soil was determined by conducting an incubation study with additions of various concentrations of K (0, 50, 100, 150, 200, 300 and 400 ppm) to soil. The incubations were carried out for different period of intervals viz. 1, 2, 4, 7, 14 and 30 days and the K was extracted and fixed K was determined. Similarly, the K releasing pattern of soil was evaluated by successive extraction with 0.01 N HCl. The results of present study revealed that the percentage K fixed showed decreasing trend with the increment in added K irrespective of the treatment. Further, the K release showed decreasing trend with increasing number of extractions and all the treatments continued to release K up to 13th extraction. Among the different treatments studied the treatments involving the application of FYM either alone or in combination with chemical fertilizers (T_6 and T_8) showed superior performance with respect to K fixation and release as compared to the other treatments.

Keywords: K fixation, K release, potassium fractions, vertisol, available-K, water soluble-K, lattice-K, exchangeable-K, non-exchangeable-K, total-K

Introduction
Potassium (K) is an essential nutrient for plant growth. It's classified as a macronutrient because plants take up large quantities of K during their life cycle (Prajapati and Modi, 2012; Mandale *et al.*, 2018) [15, 13]. Potassium is associated with the movement of water, nutrients and carbohydrates in plant tissue. It's involved with enzyme activation within the plant, which affects protein, starch and adenosine triphosphate (ATP) production. The production of ATP can regulate the rate of photosynthesis. Potassium also helps regulate the opening and closing of the stomata, which regulates the exchange of water vapor, oxygen and carbon dioxide (Mengel, 2016; Dotaniya *et al.*, 2020) [14, 6].

Potassium is the seventh most abundant element in the earth crust. The soils contain 0.04 - 3% K, the total K content of the upper 0.2 m of most agricultural soils generally ranges from 10 to 20 g kg-1 (Ramamurthy *et al.*, 2017) [17]. However, most of the soil potassium (90-98%) is chemically bound in the crystal lattice structure of minerals and thus not directly available or slowly available for plant uptake. The availability of K varies considerably from soil to soil and is affected by different properties of soil (Gurav *et al.*, 2019) [9].

Potassium fixation in soil is the phenomenon of conversion of labile pool of K i.e. soil solution and exchangeable K into moderately or slowly available non-exchangeable K, which is not readily absorbed by the plants (Rao *et al.*, 2000; Dotaniya *et al.*, 2023) [18, 8]. The occurrence of fixation of applied potassium and release of fixed K plays important role in K availability to crop plants and response to applied fertilizer K (Dotaniya *et al.*, 2022) [7]. Continuous intensive cropping without potassium administration or sub-optimal application of K or, unbalanced nutrient usage has resulted in the mining of soil K which facilitates the K fixation capacity of soil and simultaneously change the availability trend of applied K (Johnson *et al.*, 2022) [10]. The fixed K becomes available to subsequent crops over a longer period of time upon depletion of water soluble and exchangeable (Majumdar *et al.*, 2017) [12]. The soils which have high initial K status, the fixation appears to be low and becomes double due to exhaustive cropping (Rao *et al.*, 2000) [18]. The variability of K fixation in soil indirectly influences the response of crops to added fertilizer K and the K requirement to maintain soil available K status for optimum plant growth (Yadav and Sidhu, 2016) [22]. Keeping this in view, the present investigation was undertaken to assess the fixation of added potassium and release pattern in the surface soils of central India under long term application of organic, inorganic and integrated nutrients.

Materials and Methods

Study 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 western parts 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 1000mm 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 rain fall are 1781.52 mm and 919.30 mm, respectively.

Experiment details

The on-going research project initiated in 1983 on "All India Coordinated Research Project on Dry land Agriculture" was used for this investigation. The experiment was conducted with nine treatments *viz.*, T_1- unfertilized control, T_2- 20 kg N + 13 kg P ha^{-1}, T_3- 30 kg N + 20 kg P ha^{-1}, T_4- 40 kg N + 26 kg P ha^{-1}, T_5- 60 kg N + 35 kg P ha^{-1}, T_6- 6 t ha^{-1} FYM + 20 kg N + 13 kg P, T_7- 5 t ha^{-1}crop residues + 20 kg N + 13 kg P, T_8- 6 tha^{-1} FYM and T_9- 5 tha^{-1} crop residues (CR).

Experimental soil

The physico-chemical properties experimental soil was analyzed as per the method described in Singh *et al.* (2005) [20]. 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 0.54dS m^{-1}.

Soil sampling and processing

Soil samples were collected from 0-15 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 used for incubation experiment and K fixation and release were studied.

Potassium Fixation and Release study

To determine the K fixing capacity of soil, an incubation study was conducted by adding various concentrations of K (0, 50, 100, 150, 200, 300 and 400 ppm) to soil samples collected from different treatments, allowed them to incubate at room temperature for different period of intervals viz. 1, 2, 4, 7, 14 and 30 days and the K was extracted from the samples with neutral N NH4OAc and fixed K was determined (Dhaliwal *et al.* 2006) [5].

Fixed K = Added K- [Extractable K (Treated) - Extractable K (control)

The K releasing pattern of soil was evaluated by successive extraction with 0.01 N HCL. Briefly, to a two and half gram soil sample, 50 ml of 0.0 1N HCL was added, shaken for 15 minutes in a mechanical shaker, centrifuged for 10 minutes at 2000 rpm and K was estimated in the supernatant liquid. Further, to the same soil, another 50 ml of 0.01N HCI was added and the same procedure was repeated 15 times or till such time that the released K was constant or nil. This is called as constant rate-K (CR-K) where the amounts of K extracted in consecutive extraction will be similar whereas step – K was computed by subtracting the CR-K soil was computed by adding the values of K by successive extractions (Dhaliwal *et al.* 2006) [5].

Results and Discussion

K Fixation

The percentage of K fixed to that of added K at different levels of added K (50, 100, 150, 200, 300 and 400 mg kg^{-1}) under varying incubation periods (1, 2, 4, 7, 14 and 30 days) under each treatment are presented in Table 1. Similarly, the mean K-fixation at different K addition across 30 days of incubation period under studied treatments is presented in Table 2. Further, the mean K-fixation at different incubation period across K addition under these treatments is presented in Table 3.

Table 1: K-fixation (%) under different long term fertility treatments at various period of incubation

Treatment	K Levels	Period of incubation					
		1 day	2 days	4 days	7 days	14 days	30 days
T_1: Control	K50	79.8	74.8	72.8	70.1	67.2	67.2
	K100	73.2	71.8	69.9	66.2	64.3	64.2
	K150	71.1	68.2	64.2	61.9	60.1	60.2
	K200	70.5	65.3	67.5	62.2	58.7	56.9
	K300	69.9	64.2	63.0	60.3	59.9	59.4
	K400	64.5	62.2	61.3	60.4	57.6	57.5
T_2: 20 kg N + 13 kg P ha^{-1}	K50	74.5	71.3	70.8	68.1	65.3	65.3
	K100	70.5	67.9	65.8	64.2	63.4	63.4
	K150	67.3	64.2	62.9	60.2	59.6	59.5
	K200	63.2	61.3	59.0	56.5	55.0	55.0
	K300	60.1	56.9	54.1	52.8	51.6	51.6
	K400	57.2	55.3	51.4	49.0	48.8	48.5
T_3: 30 kg N + 20 kg P ha^{-1}	K50	73.2	70.1	68.2	65.2	65.0	65.0
	K100	70.1	67.2	65.3	64.1	63.8	63.8
	K150	66.5	63.6	61.5	60.3	59.6	59.7
	K200	61.9	59.2	57.1	56.1	56.0	55.9
	K300	59.4	57.4	55.4	53.9	52.8	52.8
	K400	57.6	55.3	53.2	51.3	52.0	51.9
T_4: 40 kg N + 26 kg P ha^{-1}	K50	71.9	67.4	64.8	61.9	59.2	59.2
	K100	64.3	62.7	60.2	58.2	56.8	56.8
	K150	62.9	59.3	56.1	53.0	52.4	52.4
	K200	60.8	58.3	55.3	52.2	51.6	51.6
	K300	58.4	53.2	52.8	50.8	49.2	49.2
	K400	56.1	51.4	50.2	49.1	48.5	48.5
T_5: 60 kg N + 35 kg P ha^{-1}	K50	69.8	64.8	62.8	60.1	57.2	57.2
	K100	63.2	61.8	59.9	56.2	54.3	54.2
	K150	61.1	58.2	54.2	51.9	50.1	50.2
	K200	59.2	55.3	53.2	52.2	48.7	46.9
	K300	57.3	54.2	53.0	50.3	49.9	49.4
	K400	54.5	52.2	51.3	50.4	47.6	47.5
T_6: 6 t ha^{-1}FYM + 20 kg N + 13 kg P	K50	89.3	88.5	84.2	80.9	80.1	80.1
	K100	87.9	86.2	83.3	80.1	79.5	79.5
	K150	85.2	83.6	81.3	78.5	78.2	78.2
	K200	86.0	81.2	79.4	77.1	76.9	76.8
	K300	83.2	80.5	76.2	74.9	73.3	73.3
	K400	80.9	76.3	74.5	73.0	71.4	71.4
T_7: 5 t ha^{-1}crop residues + 20 kg N + 13 kg P	K50	78.8	73.9	71.9	69.2	66.4	66.4
	K100	72.3	70.9	69.0	65.4	63.5	63.4
	K150	70.2	67.4	63.4	61.1	59.4	59.4
	K200	69.7	64.5	66.7	61.4	57.9	56.2
	K300	69.0	63.4	62.2	59.5	59.2	58.6
	K400	63.7	61.5	60.5	59.7	56.8	56.7
T_8: 6 t ha^{-1} FYM	K50	87.5	86.7	82.6	79.2	78.5	78.5
	K100	86.1	84.5	81.6	78.5	78.0	78.0
	K150	83.5	82.0	79.7	76.9	76.7	76.6
	K200	84.2	79.6	77.8	75.6	75.3	75.3
	K300	81.6	78.9	74.7	73.4	71.8	71.8
	K400	79.3	74.7	73.0	71.5	70.0	70.0
T_9: 5 t ha^{-1}crop residues	K50	78.0	73.1	71.2	68.6	65.7	65.7
	K100	71.6	70.2	68.4	64.8	62.9	62.8
	K150	69.5	66.7	62.8	60.5	58.8	58.8
	K200	69.0	63.9	66.0	60.8	57.4	55.6
	K300	68.3	62.8	61.6	58.9	58.6	58.0
	K400	63.1	60.8	59.9	59.1	56.3	56.2

The data presented in Table 2 revealed that the mean K-fixation at 50 ppm added K ranged 62.0-83.8%. The K-fixation at K levels of 100 ppm, 150 ppm, 200 ppm, 300 ppm and at 400 ppm were ranged 58.3-82.8%, 54.3-80.9%, 52.36-79.6%, 52.3-76.9% and 50.6-74.6%, respectively. The percentage K fixed showed decreasing trend with the increment in added K irrespective of the treatment. The treatments involving the application of FYM either alone or in combination with chemical fertilizers (T_6 and T_8) showed higher % of K fixation. The lowest K fixation was observed in the treatment T_5 (60 kg N + 26 kg P) across all the levels of added K.

Table 2: Mean K-fixation (%) at different K addition across 30 days incubation period under the studied treatments

Treatment	K50	K100	K150	K200	K300	K400
T_1: Control	72.0	68.3	64.3	63.5	62.8	60.6
T_2: 20 kg N + 13 kg P ha^{-1}	69.2	65.9	62.3	58.3	54.5	51.7
T_3: 30 kg N + 20 kg P ha^{-1}	67.8	65.7	61.9	57.7	55.3	53.5
T_4: 40 kg N + 26 kg P ha^{-1}	64.1	59.9	56.0	55.0	52.3	50.6
T_5: 60 kg N + 35 kg P ha^{-1}	62.0	58.3	54.3	52.6	52.4	50.6
T_6: 6 t ha^{-1}FYM + 20 kg N + 13 kg P	83.8	82.8	80.9	79.6	76.9	74.6
T_7: 5 t ha^{-1}crop residues + 20 kg N + 13 kg P	71.1	67.4	63.5	62.7	62.0	59.8
T_8: 6 t ha^{-1} FYM	82.2	81.1	79.2	78.0	75.4	73.1
T_9: 5 t ha^{-1}crop residues	70.4	66.8	62.9	62.1	61.4	59.2

Table 3: Mean K-fixation (%) at different incubation period across K addition under the studied treatments

Treatment	1 day	2 days	4 days	7 days	14 days	30 days
T_1: Control	71.5	67.8	66.5	63.5	61.3	60.9
T_2: 20 kg N + 13 kg P ha^{-1}	65.5	62.8	60.7	58.5	57.3	57.2
T_3: 30 kg N + 20 kg P ha^{-1}	64.8	62.1	60.1	58.5	58.2	58.2
T_4: 40 kg N + 26 kg P ha^{-1}	62.4	58.7	56.6	54.2	53.0	53.0
T_5: 60 kg N + 35 kg P ha^{-1}	60.9	57.8	55.7	53.5	51.3	50.9
T_6: 6 t ha^{-1} FYM + 20 kg N + 13 kg P	85.4	82.7	79.8	77.4	76.6	76.6
T_7: 5 t ha^{-1} crop residues + 20 kg N + 13 kg P	70.6	66.9	65.6	62.7	60.5	60.1
T_8: 6 t ha^{-1} FYM	83.7	81.1	78.2	75.9	75.0	75.0
T_9: 5 t ha^{-1}crop residues	69.9	66.3	65.0	62.1	59.9	59.5

Further, the mean K fixation data irrespective of K addition showed that the K fixation (%) showed reducing trend with the increase in period of incubation (Table 3). At first day of incubation the K fixation percentage ranged 60.9-85.4%. The highest K fixed was noticed in the treatment T_6 followed by the treatment T_8 (83.7%). The fixation of added K on second day of incubation ranged 57.8-82.7% under various treatments studied. The K fixed determined after 4, 7 and 14 days of incubation were ranged 55.7-79.8%, 53.5-77.4% and 51.3-76.6%, respectively. After 30 days of incubation, the data of K fixation revealed that the values were ranged 50.9-76.6% among the different treatments under study (Table 3).

K Release

The data pertaining to the results of the amount of K extracted by stepwise extraction with 0.01 N HCl and the cumulative K releasing power of soils are presented in Table 4 and Fig.1.

Table 4: K released, Constant release-K, Step-K and cumulative- K as influenced by long term fertility treatments

Treatment	K released (ppm) at different extractions													CR-K	Step-K	Cumulative-K released
	1	2	3	4	5	6	7	8	9	10	11	12	13			
T_1	84	77	61	50	37	26	22	14	8	4	2	2	2	2	364.0	389.0
T_2	81	76	58	47	34	24	21	12	6	4	2.5	2.5	2.5	2.5	361.5	370.5
T_3	77	72	53	43	31	23	19	8	5	3.5	3	3	3	3	361.5	343.5
T_4	75	70	51	41	28	21	18	7	5	2	2	2	2	2	347.5	324.0
T_5	71	66	48	46	25	18	15	5	4	2	2	1.5	1.5	1.5	334.7	305.0
T_6	106	88	73	61	49	37	28	23	12	6	4	2	1	0	391.0	495.0
T_7	91	78	67	56	47	35	16	7	3	3	3	1	1	1	374.0	412.0
T_8	102	86	70	58	46	34	25	20	11	5	3.5	2	1.5	1	388.0	468.5
T_9	89	77	65	54	43	32	27	21	10	5	3.5	3.5	2.5	1.5	371.0	433.5

(T_1: Control, T_2: 20 kg N + 13 kg P ha^{-1}, T_3: 30 kg N + 20 kg P ha^{-1}, T_4: 40 kg N + 26 kg P ha^{-1}, T_5: 60 kg N + 35 kg P ha^{-1}, T_6: 6 t ha^{-1}FYM + 20 kg N + 13 kg P, T_7: 5 t ha^{-1}crop residues + 20 kg N + 13 kg P, T_8: 6 t ha^{-1}FYM and T_9: 5 t ha^{-1}crop residues)

The results indicated that considerable variation in the K releasing power was noticed among the different treatments. Generally, the quantity of K extracted from the soils gradually decreased from first extraction to 13th extraction by the time, most of the soils released very little K. Treatment T_6 released the highest K (106 ppm) and Treatment T_5 released the lowest K (71 ppm) in the first extraction. The treatment T_6, a fine textured soil with high exchangeable K and K saturation at edge position possibly held the K with less tenacity and bondage which led to rapid K release. Moreover, these soils having clay minerals with montmorillonites released more of K. During the second extraction also T_6 released K in high magnitude (88ppm) followed by Treatment T_8 (86 ppm). The lowest amount of K release (66 ppm) was obtained in T_5. Between third and eleventh extractions, most of the treatments released little amount of K. All Treatments continued to release K up to 13th extraction.

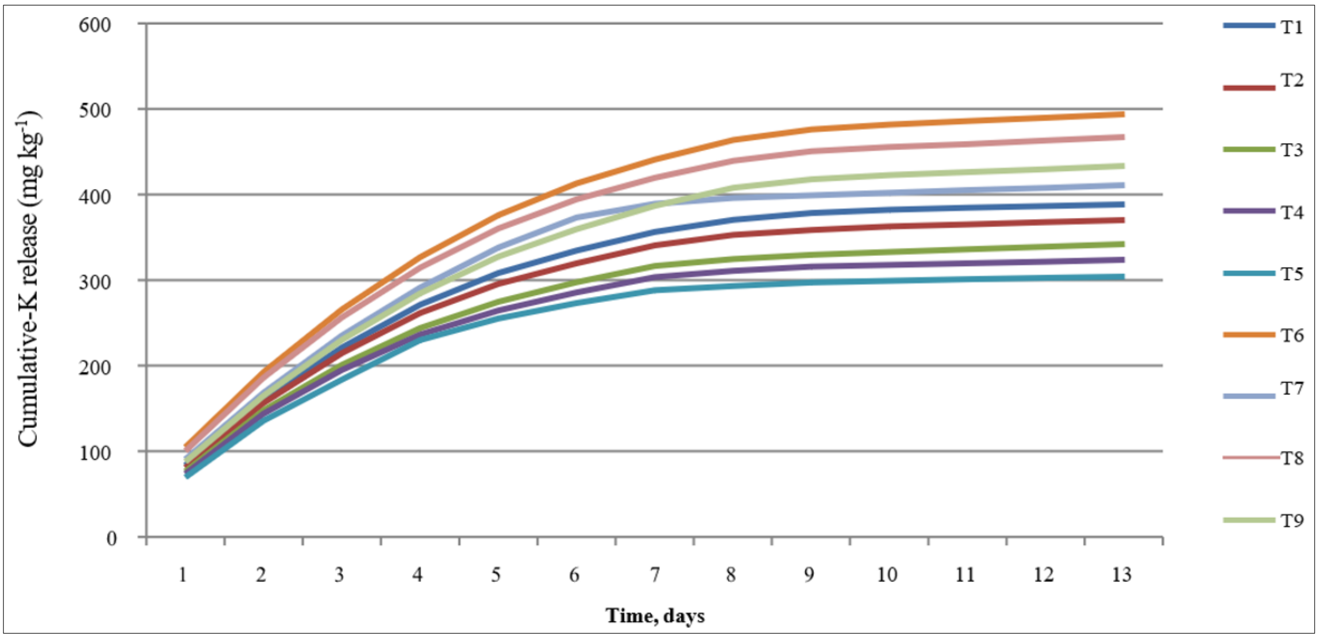

Fig 1: Cumulative K- release as affected by long term fertility treatment

Such variation in the K release pattern among different treatments could be attributed to the differences in bonding energy with which clay is held over clay lattices. Step-K provides an estimation of K availability from the non-exchangeable source and constant rate K (CR-K) is a measure of difficultly available K of the mineral lattice sources. The values of total step-K varied from 334.7 to 391.0 ppm. This indicated that the more the amount of step- K, more will be the plant utilizable non-exchangeable K from micaceous minerals under K stress situation. The constant rate K ranged from 1 to 3 ppm in different treatments.

In respect of cumulative K release power, it was observed that the highest release of K was recorded in T_6 (495.0 ppm) followed by T_8 (468 ppm), T_9 (433 ppm), T_7 (412 ppm), T_1 (389 ppm), T_2 (370 ppm), T_3 (343 ppm), T_4 (324.0 ppm) and T_5 (305.0 ppm). Low binding energy might be the reason for higher clay release in the treatments were organic applied with or without fertilizer application.

Discussion

The extent of K fixation at different levels of added K (0, 50, 100, 150, 200, 300 and 400 ppm) under varying incubation periods (1, 2, 4, 7, 14 and 30 days) and the percentage of K fixed to that of added K under each treatment are presented in Table 1. The added K levels resulted in significant variations in K fixation. From the data, it was clear that there was progressive increase in the K fixation as the concentration of added K increased irrespective of treatment which might be due to larger proportion of K being forced into inter-lattice position from labile pool as influenced by the concentration gradient (Datta *et al.*, 2011) [4]. When the magnitude of K fixation was considered from the percentage of K fixation at different levels of added K, it decreased with increasing K levels in all the treatments and this could be attributed to the saturation of specific adsorption sites for K fixation with progressive increase in the levels of added K (Das *et al.*, 2019) [2]. This could be explained by the increase in the concentration of K from solution and exchangeable sites to non-exchangeable positions are increased as a result of the increase in concentration gradient (Madar *et al.*, 2020) [11]. Thus, K fixation in the soil under different treatments increased by increasing amount of added-K. Similar results were also reported by Dhaliwal *et al.* (2006) [5] and Das *et al.* (2021) [3]. Rehman *et al.* (2020) [23] reported that the amount of K fixation increased with the increase in the amount of K. Among the incubation periods, the fixation was lowest during the first day and the same increased when the incubation period was extended to 1 day in case of T_6, T_8, T_1, T_7 and the incubation period was extended up to 2 days in case of T_6 and T_8.These results indicate that the rate of adsorption was greater initially which declined gradually until equilibrium was reached. Increasing fixation of K with varying time of contact in different soils was also revealed by Datta (2011) [4].

The results of the amount of K extracted by stepwise extraction with 0.01 N HCl and the cumulative K releasing power of soils are presented in Table 4.The results indicated that considerable variation in the K releasing power was noticed among the different treatments. Generally, the quantity of K extracted from the soils gradually decreased from first extraction to 13th extraction by the time, most of the soils released very little K. Treatment T_6 released the highest K (106 ppm) and Treatment T_5 released the lowest K (71 ppm) in the first extraction. The treatment T_6, a fine textured soil with high exchangeable K and K saturation at edge position possibly held the K with less tenacity and bondage which led to rapid K release Datta *et al.* (2011) [4]. Moreover, these soils having clay minerals with montmorillonites released more of K. Similar results were reported by Das *et al.* (2019) [2], Shakeri and Abtahi (2019) [19], Madar *et al.* (2020) [11], Das *et al.* (2021) [3] and Dotaniya *et al.* (2023) [8]. The mean values of K release in the first extraction accounted for 20.89 percent of cumulative K while at thirteenth extraction it was 0.0047 percent. Thus, the magnitude of K release decreased with the number of extractions (Dhaliwal *et al.*, 2006) [5].

Conclusion

The potassium supplying capacity of soil is not only depends on the available K content of soil, but also depends on the K fixation and release behavior. 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 the percentage

K fixed showed decreasing trend with the increment in added K irrespective of the treatment. Further, the K release showed decreasing trend with increasing number of extractions and all the treatments continued to release K up to 13th extraction. Among the different treatments studied the treatments involving the application of FYM either alone or in combination with chemical fertilizers (T_6 and T_8) showed superior performance with respect to K fixation and release as compared to the other treatments.

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