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Long term effect of fertilizers and manure on K-fractions in inceptisol under pearl millet-mustard cropping system

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Abstract
The present study conducted under ongoing long term fertilizers experiment was aimed on the effect of inorganic fertilizers with or without organic manure on yield, potassium uptake and distribution of potassium fractions after ten years of pearl millet-mustard cropping sequence during 2012-13 in an Inceptisol. The investigations revealed that the maximum yield of pearl millet (4.13 t ha^{-1}) and mustard (2.43 t ha^{-1}) and K-uptake by them was obtained with the treatment 100% NPK + FYM + Azo. + PSB, followed by the treatment receiving 100% NPK +FYM and 150% NPK. Available –K was found to be maximum with 100% NPK + FYM+Azo.+PSB (213 kg ha^{-1}), followed by 100% NPK + FYM (212 kg ha^{-1}). Moreover K-fractions Water soluble and exchangeable forms of K were found to be decreased with increasing soil depths whereas, non-exchangeable, lattice and total-K showed reverse trend in all the treatments under study. The contribution of different K fractions at various soil depths studied was in order of lattice> non-exchangeable> exchangeable > water soluble. All the K-fraction at 0-30 cm soil depth exhibited significant and positive correlation with yield. Minimum depletion of K rate was recorded in 100% NPK + FYM+ Azo.+ PSB (-3.7 kg ha^{-1} yr^{-1}) to that of other treatments, while control showed maximum K depletion rate (-10.1 kg ha^{-1} yr^{-1}) apparent K-balance in soil was lowest -100.4 kg $ha^{-1} yr^{-1}$ in control plot followed by -104.8 kg $ha^{-1} yr^{-1}$ in treatment 50% NPK+FYM. Hence, much attention is required for potassic fertilizers to maintain K status of soil and to prevent K mining. Thus, results of the experiment indicate that the depleting K reserves even at its optimal application rates points towards taking a fresh look at the existing recommendation for pearl millet and mustard crops.

Keywords: Potassium fractions, inorganic fertilizers, farmyard manure, K uptake

Introduction
Potassium (K) is the third important essential element required for plant growth which exists in soil in four different forms, viz. water soluble - K, which is taken up directly by plants; exchangeable –K, held by negative charges on clay particles and is available to plants; fixed –K, trapped between layers of expanding lattice clays; and lattice –K, an integral part of primary K bearing minerals. The knowledge of various forms of K viz., water soluble, exchangeable and non-exchangeable and an understanding conditions controlling their availability to growing crops is important for the appraisal of the available K in the soil. The available K constitutes only 1-2% of total K and exists in soil in two forms i.e. water soluble and exchangeable K adsorbed on soil colloidal surface (Brady and Well 2002) [3]. These forms remain in a dynamic equilibrium with one another. The readily available or water soluble K has been reported to be a dominant fraction in the initial stage while exchangeable and non-exchangeable K contribute more in the later stage of the plant growth (Sharma *et al.* 2009) [7]. Under intensive cultivation, readily available and exchangeable K is removed by crops. This is followed by further release of K from non-exchangeable forms. Dynamic equilibrium affected when applied K is either taken up by plants or leached into the lower soil horizons or converted into unavailable form. Under this situation, non-exchangeable –K plays an important role by releasing K to exchangeable and solution forms. The dynamics of K in soil depends on the rate of application and mining of K from the system (Pannu *et al.* 2002) [5].
Pearl millet – mustard cropping sequence got popularized during last several years under limited and assured irrigated condition, in alluvial soil region of Northern Madhya Pradesh. Although most of the alluvial soils have been reported to be rich in potassium but intensive cultivation of high yielding varieties of crops in multiple cropping system and continuous

application of N and P without K fertilizers at optimum and high rates accelerate the depletion of K and consequent response of K fertilizer (Subbarao *et al;* 1993) [12]. To formulate sound fertilizer recommendation, knowledge of potassium supplying capacity of soil is essential. This will depend not only on the available K content of soil, but a sound knowledge of different forms of K and their relationship with each other is also required. In view of this, the present study was carried out to understand the K transformation processes and input-output balance as influenced by different nutrients management practices in pearlmillet-mustard cropping system.

Materials and Methods

This study is a part of an ongoing long term fertilizers experiment with pearl millet – mustard cropping sequence initiated during 2003 at the experimental farm of Rajmata Vijayraje Sciendia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh ($26^0$13' N latitude and longitude $76^0$10' E longitude). The experimental soil was alluvial, sandy clay loam in nature and belonging to Inceptisol, hyperthermic family of Typic Ustochrept and had pH of 7.88, EC 0.38 dSm^{-1}, Organic carbon 3.88 g kg^{-1}. The soil available N, P and K were 202.8, 8.6 and 250 kg ha^{-1}, respectively. The recommended N, P and K dose, based on initial soil test, was 80 kg N, 40 kg P_2O_5 and 20 kg K_2O ha^{-1} for pearl millet and 100 kg N, 60 kg P_2O_5 and 40 kg K_2O for mustard. The sources of N, P and K used were urea, single superphosphate and muriate of potash. In sulphur – free treatment, diammonium phosphate (DAP) was used instead of SSP as source of P. Farm yard manure @ 10 t ha^{-1} yr^{-1} was applied only to pearl millet crop during *Kharif* season. Pearl millet and mustard varieties used were JBV-3 and Pusa bold respectively, pearl millet in general was sown on the onset of moon soon (first to second week of July) as rainfed during *Kharif* and mustard in the third to fourth week of October as irrigated during *Rabi*. Crops were harvested at maturity and yield data were recorded after threshing.

The profile soil samples were collected after the harvest of mustard crop during 2012-13 with the help of a tube auger (stainless steel) from each plot. The samples were drawn from 0-15, 15-30 and 30-60 cm soil depths. Basic soil parameters were estimated using standard laboratory methods. These samples were analyzed flame photo - metrically for water soluble, exchangeable, non-exchangeable, lattice and total-K. The water soluble –K was estimated in 1:5 (soil: water suspension) as described by Black (1965) [2], exchangeable-K was extracted by neutral ammonium acetate (1N) extraction in 1:5 ratio. Non-exchangeable-K was estimated by boiling soil with 1N HNO_3 in 1:10 (Soil: acid suspension) for 10 min as described by Black (1965) [2]. For the total-K determination, soil was digested with hydrofluoric (48%) and perchloric (70-72%) acid in platinum crucible by the method outlined by Black (1965) [2]. Lattice-K was estimated by difference between total-K and sum of water soluble, exchangeable and non-exchangeable-K.

Results and Discussion

The basic soil properties of the profile (Table-1) indicated considerable variation with treatment levels at different soil depths. The soil pH varied from 7.50 to 7.89, EC ranged from 0.10 to 0.19 dSm^{-1} and increased with soil depth. While the organic carbon content of the soil varied from 2.20 g kg^{-1} in control plot to 6.52 g kg^{-1} in 100% NPK +FYM + Azo.+ PSB and registered a decreasing trend with increasing soil depth. Similar observations were also noted by Thakur *et al.* (2011) [13] who found decreasing trend of organic carbon with increase in soil depth.

Distribution of potassium fractions

The water soluble-K in the K applied plots was significantly higher than those of without K applied or unfertilized (control) plots at all soil depths studied. The water soluble-K ranged from 3.1 to 14.6, 2.9 to 10.3 and 2.2 to 9.7 mg kg^{-1} in 0-15, 15-30 and 30-60 cm soil depths, respectively (Table 2). There was a further increase in water soluble-K under NPK +FYM amended plots over the NPK treated plot at all the soil depths. Such an increase in the content of water soluble-K might be due to addition of organic materials as reported earlier (Sood *et al.* 2008) [10]. The exchangeable K varied from 72.7 to 126.5, 72.7 to110.2 and 70.5 to 106.2 mg kg^{-1} in 0-15, 15-30 and 30-60 cm soil depths, respectively (Table 2). Exchangeable K increased in all the K applied treatments in comparison to control and without K applied plots. Application of FYM + Azo. + PSB along with 100% NPK recorded higher values of exchangeable-K followed by 100% NPK+FYM and 150 % NPK treatments. The higher amounts of exchangeable K in the FYM treated plots over the years may be ascribed to the fact that FYM addition could increase the CEC of soil which was responsible for holding more amount of exchangeable-K and helped in the release of exchangeable-K from non-exchangeable pool (Yaduvanshi and Swarup, 2006) [15]. Besides this K content of FYM also increased its concentration in soil.

Considerable depletion of non-exchangeable-K content was observed at all the soil depths studied after 10 cropping cycles for all treatments over its initial level (1242 & 1293 mg kg^{-1} at 0-15 & 15-30 cm depth). The non-exchangeable-K was ranged from 852 mg kg^{-1} in surface layer of 100% N treatment to a maximum of 1256 mg kg^{-1} for the 30-60 cm soil depth in 150% NPK treated plot (Table 2). A remarkable depletion of lattice-K content was noticed at all soil depths studied after 10 years of intensive cropping with pearl millet and mustard. Highest value of lattice –K was in 100% NPK +FYM +Azo. +PSB followed by 150% NPK. Lowest value of lattice –K was found in 100% NP plots at all soil depths. The total K content was significantly the highest (11477 mg kg^{-1}) under 150% NPK closely followed (11440) by 100% NPK +FYM +Azo. +PSB than that of without K applied plots. The total K content revealed a declining trend with control and without-K treated plots, as a result of higher rates of K removal by the crop. The higher build up was noticed in treatment receiving 150 % NPK level. The results are in conformity to the findings of Singh and Singh (2001) [9].

Results further indicate that water soluble and exchangeable forms of K decreased with increasing soil depths whereas, non-exchangeable, lattice and total-K showed reverse trend in all the treatments under study. Higher amount of water soluble and exchangeable K in surface layer may be attributed to the accumulation of K applied through the organic material and fertilizers. Similar distribution of water soluble and exchangeable K in surface and sub-surface horizon were also reported by Srinivasa Rao *et al*. (1997) [11]. The increase in non-exchangeable K at lower horizon was explained in the basis that its conversion to exchangeable form could not take places and also due to lesser K depletion by the plant roots as compared to the surface layer, where rooting density might be maximum. Pannu *et al.* (2002) [5] suggested that when movement of K in soil solution was restricted permeability in lower horizon. This might have slowed down the movement of aqueous phase there by providing ample time for K to diffuse in to the clay lattice. Thus, the non-exchangeable K increased and exchangeable K decreased with increase in soil depths. All K fractions depleted from its initial levels under different treatments except 150% NPK or 100% NPK + FYM treated plots. The results are in line with the findings of Bhattacharyya *et al.* (2008) [1].

Grain yields and potassium uptake

The pooled data on grain yield of pearlmillet and mustard are presented in table 3. The lowest grain yields of pearl millet and mustard 2.06 and 1.05 t ha^{-1}, respectively were recorded in control. On the other hand, grain yield obtained in 100% NPK + FYM +Azo. +PSB treatment (4.13 and 2.43 t ha^{-1} in pearl millet and mustard, respectively) was significantly higher than other treatments. The 150% NPK treatment was found to be at par with the application of 100% NPK + FYM under pearl millet yield but was significantly inferior in case of mustard grain yield. Inclusion of K along with NP (100% NPK) caused an increase around 15.4 and 11.2 % over application of 100% NP alone in pearl millet and mustard, respectively. The application of organic manure (10 t FYM ha^{-1} yr^{-1}) along with NPK dose (50, 75 and 100% NPK) was observed to be beneficial in enhancing the crop productivity of pearl millet and mustard over their respective NPK alone (Table 3). The beneficial effect of FYM can be attributed to steady supply of all nutrients including the micronutrients and improvements in physical condition of soil. The similar beneficial effects of FYM along with NPK have been reported by Tiwari *et al.* (2002) [4].

Total K uptake varied from 65.5 to 167.8 kg ha^{-1} in pearl millet and 44.9 to 118.3 kg ha^{-1}in mustard, respectively. The highest K uptake was found in 100% NPK + FYM +Azo. +PSB, followed by 100% NPK + FYM and 150% NPK treatments and these treatments were statistically at par among them and the lowest uptake was observed in control plots in both the crops. Similar findings were also reported by Dwivedi *et al*. (2007) [4] who found maximum K uptake with the treatment of integrated use of organic manure and recommended fertilizer dose as compared to control plot.

Potassium input and output balance

Analysis of results for the last 10 years showed that the mean annual removal of K by crops surpassed the amount of total K applied to the soil in all treatments (Table 4 and 5). Thus showing a net negative K balance ranging from -100.4 kg ha^{-1} yr^{-1} in control plot to -177.0 kg ha^{-1} yr^{-1} in 100% NP treated plots. The application of NPK + FYM to soils resulted in a greater negative K balance than that of the unfertilized control. The removal of K -124.4 kg ha^{-1} yr^{-1} in the 100% NPK +FYM treatment plot over 100% NPK treatments (-163.1 kg ha^{-1} yr^{-1}) could be ascribed to other benefits of FYM application such as additional nutrient supply, less loss of nutrient from the soil and improved soil physical properties apart from added K nutrient (Singh and Wanjari, 2012) [8].

The perusal of data revealed a declining trend (37 to 101 kg ha^{-1}) as compared to its initial level (250 kg ha^{-1}) of available K status which indicates considerable mining of available K after 10 years of intensive cropping (Table-4). Maximum decline (-101 kg ha^{-1}) was observed in control followed by 100% NP (-97 kg ha^{-1}). The magnitude of decline decreased with increasing levels of NPK application. Among the inorganic fertilizers, continuous application of N, NP adversely affected the available K content of the soil, which may be attributed to non application of potassic fertilizer, which also resulted in nutrient imbalance in the soil. Continuous omission of K in pearl millet- mustard caused mining of its native pools also resulted reduction in yield (Dwivedi *et al*; 2007) [4]. Highest available K status (213 kg ha^{-1}) of soil was found in the treatment 100% NPK+FYM + Azo. +PSB followed by100% NPK+FYM (212 kg ha^{-1}). Bhattacharyya *et al.* (2008) [1] opined that organic matter might have caused reduction in K fixation and consequentially increased available K content due to interaction of organic matter with clay, besides the direct addition to the available K pools of soil. From the results it is evident that the present K recommendations are not sufficient and need revision; otherwise there is a possibility of abrupt K mining and as a result decline in production in near future.

Relationship of potassium fractions with mustard yields

Table 6 revealed the correlation of coefficient between forms of K and yield of mustard. The maximum and positive significant correlation was found with total-K followed by lattice-K. the correlation coefficient with water soluble-K and yield was estimated to be lowest in all the fractions considered here. Thus, it could be concluded that total-K and lattice-K should be taken into consideration while giving recommendations for increasing the mustard yield. The results are in conformity with the findings of Sawarkar *et al.* (2013) [6].

Table 1: Distribution of basic soil properties in soil profile

Treatments	Soil pH (1:2)			Electrical Conductivity (dSm^{-1})			Organic Carbon (g kg^{-1})		
	Soil depth (cm)								
	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
T_1-Control	7.80	7.80	7.83	0.10	0.11	0.11	3.42	2.47	2.20
T_2-50%NPK	7.79	7.80	7.83	0.11	0.12	0.11	4.24	3.23	2.65
T_3-75%NPK	7.74	7.76	7.80	0.11	0.12	0.12	4.39	3.43	2.71
T_4-100%NPK	7.68	7.74	7.77	0.12	0.13	0.13	4.59	3.59	2.80
T_5-150%NPK	7.70	7.75	7.80	0.11	0.12	0.12	6.25	5.44	4.52
T_6-100%NP	7.73	7.78	7.80	0.10	0.12	0.12	4.14	3.52	2.88
T_7-100%N	7.80	7.89	7.87	0.11	0.10	0.10	3.88	3.03	2.52
T_8-100%NPK-S	7.73	7.79	7.81	0.11	0.12	0.13	4.04	3.02	2.45
T_9-50%NPK+FYM	7.75	7.77	7.80	0.11	0.13	0.15	4.35	3.05	2.11
T_{10}-75%NPK+FYM	7.69	7.73	7.76	0.12	0.14	0.15	4.51	3.16	2.21
T_{11}-100%NPK+FYM	7.58	7.69	7.75	0.13	0.16	0.18	5.69	4.84	3.17
T_{12}100%NPK+FYM+AZO+PSB	7.52	7.52	7.72	0.12	0.18	0.19	6.52	5.25	3.88
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.14	0.09	0.06
Initial value (2003)	7.78	7.80	-	0.12	0.14	-	3.65	2.68	-

Table 2: Distribution of potassium fraction (mg kg^{-1}) in soil profile

Treatments	Water Soluble-K			Exchangeable -K			Non- exchangeable-K			Lattice-K			Total – K		
	Soil depth (cm)														
	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
T_1-Control	3.1	2.9	2.2	76.3	75.2	72.6	883	922	938	8868	8950	9027	9830	9950	10040
T_2-50%NPK	4.9	3.5	3.2	87.1	82.2	78.5	943	976	988	9065	9208	9580	10100	10270	10650
T_3-75%NPK	6.1	5.9	5.4	90.3	88.8	80.6	1014	1059	1068	9450	9746	9826	10560	10900	10980
T_4-100%NPK	7.2	8.1	7.8	105.2	98.0	92.5	1105	1196	1220	9663	9828	9930	10880	11130	11250
T_5-150%NPK	12.3	10.3	9.7	116.4	110.2	106.2	1202	1234	1256	9829	10068	10105	11160	11423	11477
T_6-100%NP	4.2	4.2	3.8	72.9	72.7	70.5	852	918	932	7991	8825	8914	8920	9820	9920
T_7-100%N	4.1	4.0	3.6	79.6	76.4	72.6	872	973	988	8144	8917	8921	9100	9970	9985
T_8-100%NPK-S	7.4	7.4	7.2	103.6	96.4	92.6	1085	1179	1192	9564	9757	9893	10760	11040	11185
T_9-50%NPK+FYM	5.9	5.2	4.6	98.2	93.2	90.2	906	958	966	9000	9494	9614	10010	10550	10675
T_{10}-75%NPK+FYM	8.9	6.7	6.2	109.4	98.5	94.5	1002	1053	1068	9640	9712	9891	10760	10870	11060
T_{11}-100%NPK+FYM	14.3	8.3	7.5	123.3	105.3	98.7	1076	1133	1145	9736	9933	10064	10950	11180	11315
T_{12}100%NPK+FYM+AZO+PSB	14.6	9.7	8.8	126.5	106.4	101.4	1085	1149	1170	9834	9985	10160	11060	11250	11440
CD (P=0.05)	1.4	1.2	1.2	9.2	7.8	7.2	68	84	92	422	488	502	505	514	526
Initial value (2003)	9.14	8.50	-	110.3	102.8	-	1242	1293	-	10130	10280	-	11490	11684	-

Table 3: Effect of different treatments on yield and K uptake by pearl millet and mustard (pooled data for 10 year)

Treatments	Grain yield (t ha^{-1})		Total K uptake (kg ha^{-1})	
	Pearlmillet	Mustard	Pearlmillet	Mustard
T_1-Control	2.06	1.05	55.5	44.90
T_2-50%NPK	2.95	1.64	83.3	66.96
T_3-75%NPK	3.21	1.82	104.7	75.27
T_4-100%NPK	3.68	1.98	119.5	103.60
T_5-150%NPK	3.85	2.16	127.1	114.34
T_6-100%NP	3.19	1.78	104.3	72.70
T_7-100%N	2.63	1.32	82.2	57.64
T_8-100%NPK-S	3.49	1.66	103.3	92.29
T_9-50%NPK+FYM	3.26	1.88	100.2	97.05
T_{10}-75%NPK+FYM	3.48	2.08	116.7	104.93
T_{11}-100%NPK+FYM	3.85	2.31	135.2	111.65
T_{12}100%NPK+FYM+AZO+PSB	4.13	2.43	137.8	118.30
CD (P=0.05)	0.18	0.12	15.24	12.48

Table 4: Effect of different treatments on available K after 12 cycles

Treatments	Available-K (kg ha^{-1})	Changes from initial (kg ha^{-1})	D/B (kg ha^{-1} yr^{-1})
T_1-Control	149	-101	-10.1
T_2-50%NPK	176	-74	-7.4
T_3-75%NPK	185	-65	-6.5
T_4-100%NPK	188	-62	-6.2
T_5-150%NPK	195	-55	-5.5
T_6-100%NP	153	-97	-9.7
T_7-100%N	156	-94	-9.4
T_8-100%NPK-S	194	-56	-5.6
T_9-50%NPK+FYM	191	-59	-5.9
T_{10}-75%NPK+FYM	199	-51	-5.1
T_{11}-100%NPK+FYM	212	-38	-3.8
T_{12}100%NPK+FYM+AZO+PSB	213	-37	-3.7
CD (P=0.05)	8.6	-	-
Initial status	250	-	-

Table 5: Apparent potassium balance in soil after 10 years of pearl millet mustard cropping system

Treatments	Total K added (kg ha^{-1})	Total K uptake (kg ha^{-1})	Apparent K balance (kg ha^{-1})	K balance (kg ha^{-1} yr^{-1})
T_1-Control	0	1004	-1004	-100.4
T_2-50%NPK	300	1503	-1203	-120.3
T_3-75%NPK	450	1800	-1350	-135.0
T_4-100%NPK	600	2231	-1631	-163.1
T_5-150%NPK	750	2414	-1664	-166.4
T_6-100%NP	0	1770	-1770	-177.0
T_7-100%N	0	1398	-1398	-139.8
T_8-100%NPK-S	500	1956	-1456	-145.6
T_9-50%NPK+FYM	925	1973	-1048	-104.8
T_{10}-75%NPK+FYM	1075	2216	-1141	-114.1
T_{11}-100%NPK+FYM	1225	2469	-1244	-124.4
T_{12}100%NPK+FYM+AZO+PSB	1225	2561	-1336	-133.6

Table 6: Correlation between mustard yield and K fractions

K-fractions	Correlation values
Water soluble-K	0.358*
Exchangeable -K	0.412**
Non-exchangeable-K	0.488**
Lattice-K	0.548**
Total-K	0.654**

Conclusion

From the results obtained under long term experiment with continuous addition of fertilizers for last 10 years in alluvial soil improved the basic properties of the soil. Continuous use of inorganic fertilizers and organic manures improved potassium fractions in soil over control but resulted in negative balance of potassium over 10 years of pearl millet-mustard cropping sequence. Water soluble and exchangeable forms of K were found to be decreased with increasing soil depths whereas, non-exchangeable, lattice and total-K show reverse trend in all the treatments under study. The contribution of different K fractions at various soil depths studied was in order of lattice> non-exchangeable> exchangeable > water soluble. Integration of FYM with different levels of NPK increased the productivity of pearl millet and mustard over NPK alone. Potassium fractions exhibited significant and positive correlation with yield. Thus, finding of the present investigation indicate that the depleting K reserves even at its optimal application rates point towards a relook at the existing recommendation for pearl millet and mustard crops.

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