Potassium Fertility of Indian Bench-mark Soils

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Introduction

In India, until the eighties, potassium did not receive much attention because of the general belief that Indian soils were well supplied with potassium. In fact, crop removal of potassium often equals or exceeds that of nitrogen. Bansal and Umar (1998) estimated that a total of 13.7 million tones of K_2O/year is being removed by crops in India against the present fertilizer consumption of only 1.57 million tones of K_2O. After considering all the organic and inorganic additions, a net deficit of 7.049 million tones K_2O per year has been estimated which means a depletion of Indian soils at the rate of 37.5 kg K_2O/ha/year.

In light of the above facts, one may ask about the developing potassium deficiency in soils consequent upon the intensive cropping with relatively higher rates of N and P application with practically very little K application. In fact, this is even more evident from the nutrient use ratios in the country and in different regions as well. At present the N : P_2O_5 : K_2O consumption ratio in the country is 1.0 : 0.38 : 0.14 while in the northern India, it is highly unbalanced at 1.0 : 0.29 : 0.034 as the K use in the intensively cultivated states of Punjab, Haryana and Uttar Pradesh is almost negligible. Due to this imparity in nutrient use, numerous examples of soil K depletion from intensively cultivated areas of Punjab, U.P. and other states etc. have emerged. In future, these cases are bound to further multiply and the situation will aggravate.

As we know that intensive cropping with high yielding varieties makes considerable demand on the soil nutrient resources, it is therefore, quite likely that even those soils which are considered sufficient in available potassium may not be able to maintain this condition for long. However, till recently, little attention was being paid to the potassium application to field crops except some commercially important ones.

There were several reasons for this lack of interest in potassium fertilization. Firstly, experiments conducted till the fifties did not bring out clearcut crop responses to potassium. In fact, Stewart (1947) who submitted his report on soil fertility research in the country clearly stated that all Indian soils are sufficient in K except the lateritic ones. This resulted in setting up of numerous simple fertilizer trials on cultivators' fields under the Technical Co-operation Mission of the USA. The results obtained from these field experiments on different cereal, oilseed and cash crops during the last four decades have conclusively shown that application of potassic fertilizers is beneficial and significant crop responses are quite common in Indian soils.

Potassium Fertility Maps of Indian soils

Potassium fertility of Indian soils has been investigated and mapped first by Ramamoorthy and Bajaj in 1969 and subsequently by Ghosh and Hassan in 1976. Accordingly, potassium deficiency was quite widespread in the eastern and northeastern states and fairly common in the states of J & K, Kerala and Uttar Pradesh. A gross comparison of these two maps suggest that the K supply position of the soils improved during the course of 7 years, because in 1976, 11% more districts were high rather than medium in soil K. However, a closer examination of the data showed that the districts classified as medium in available soil K decreased from 53% in 1969 to 42% in 1976, but with a concomitant increase in high category, from 27% to 38%. This discrepancy could be attributed to the poor representative character of sampling, non-cognizance of pedological classification of soils. Also, the critical limits for soil classification of soils into low, medium and high K categories have been taken to be identical for all soils, irrespective of their mineralogy and amounts of non-exchangeable K. Accordingly, K-fertility maps drawn on the basis have only limited utility in developing meaningful recommendations or monitoring soil fertility changes. In its report, the National Commission on Agricultural (1976) pointed out that a sounder basis for soil fertility investigations would be to systematically analyze samples of identified soil series. Soil series are distinguished on the basis of profile characteristics and on chemical and mineralogical properties of soils. Recommendations formulated on the basis of soil series can be extended to similar areas with a larger degree of confidence. Moreover, the bench-mark sites provide an excellent opportunity to monitor the changes in soil K fertility under actual farmers' conditions of cropping and fertilization.

Based on established agroecological regions of NBSS & LUP, Nagpur and published information on available and reserve K of soils, different agroecological regions have been categorized for K fertility (Subbarao and Srinivasarao, 1996). It indicated that many regions i.e., 14,15, 19, 8, 12 were low in available K. Regions 2, 7, 20, 14, 15,19, 8, 12, and 21 were having soils of low reserve K**.**

The NBSS&LUP of ICAR has compiled a comprehensive information on the benchmark soil series of India twice. First, information on 84 soil series was listed while in the later publication, 180 benchmark soil series have been described. At the PRII, 29 benchmark soil series were studied in detail. In the present paper, we have attempted to review the potassium fertility status of Indian benchmark soils and the factors influencing the K availability in these soils.

Potassium fertility status of benchmark soils

A limited information on potassium fertility in 109 out of the 180-benchmark soil series is available on the basis of N NH_4OAc-extractable K and a map has been prepared at PRII. Although this information is not sufficient to describe the status of K availability in soils differing in amount and nature of clay present due to the lack of inter-correlation among the soil series and also information on the extent of their distribution, yet the map can give a fair idea of the geographical distribution of K deficiency / sufficiency. Accordingly, out of the 109 soils series, 17.5% were low, 40% were medium and 42.5% were high in available K. Low fertility soils series were reported to occur mainly in states of Punjab, West Bengal, Karnataka, Rajasthan, Maharashtra and Madhya Pradesh. Information on reserve K was not available which limited the utility of this information.

Out of 29 bench-mark soil series studied in detail by PRII (Sekhon *et al.*, 1992), about 30% were marginal, 30% were medium and the remaining 40% were sufficient in the native supply of potassium (**Table 1**). Accordingly, the deficient soils were in the states of West Bengal (Birbhum distt.), Orissa (Puri distt.) and Andhra Pradesh (Nalgonda distt.) and Kerala (Trivendrum distt.) and Maharashtra (Ratnagiri distt on the West Coast) besides a soil each in Southern Karnataka (Bangalore distt.) and Kashmir (Anantnag distt.).

Besides available K, reserve K status of these soils was also studied by

Table 1: Potassium Fertility of 29 Bench mark soil series of India

Soil series	*NH_4OAc-K (mg/kg ± SD)*	*HNO_3-K (mg/kg ± SD)*	*Fertility rating*	
			Available-K	*Reserve-K*
a) Alluvial				
Lidder (J&K)	49± 22	430 ± 77	Low	Low
Bagru (H.P.)	94± 37	346±64	Medium	Low
Nabha (Punjab)	104± 54	965 ± 255	Medium	High
Lukhi (Haryana)	78± 45	618 ± 159	Low	Low
Masitawali (Rajasthan)	251± 84	1310±313	High	High
Akbarpur (U.P.)	125± 41	1448±203	Medium	High
Rarha (U.P.)	95±33	1531±353	Medium	High
Khatki (U.P.)	99± 22	1494±212	Medium	High
Balisahi (Orissa)	30± 14	92±34	Low	Low
Jagdishpur Bagha (Bihar)	79± 58	1753±220	Medium	High
Raghopur (Bihar)	89± 29	2115±408	Medium	High
Hanrgram (W.B.)	132± 53	425±160	High	Low
Kharbona (W.B.)	42± 17	119±34	Low	Low
Chandole (A.P.)	424± 233	1030±565	High	High
b) Red				
Kodad (A.P.)	70± 32	266 ± 70	Low	Low
Vijayapura (Karnataka)	68± 43	127 ± 57	Low	Low
Tyamagondalu (Karnataka)	76± 27	365 ± 12	Low	Low
Doddabhavi (Tamil Nadu)	92± 31	1049 ± 239	Medium	High
c) Laterites				
Kumbhave-5 (Maharashtra)	70± 35	189± 72	Low	Low
Nedumangad (Kerala)	69± 33	120± 38	Low	Low
d) Arid soil				
Mazodar (Gujarat)	109± 55	606± 167	Medium	Low
e) Vertisols & Veric type soils				
Sarol (M.P.)	348 ± 88	769±252	High	Low
Kamaliakheri (M.P.)	279± 75	603± 182	High	Low
Pithvajal (Gujarat)	407 ± 89	776±173	High	Low
Shendvada (Maharashtra)	482± 81	1024± 187	High	High
Pemberty (A.P.)	216± 50	711± 133	High	Low
Noyyal (T.N.)	688 ± 132	2339±276	High	High
Kalathur (T.N.)	193± 38	893 ± 102	High	Low
f) Acid sulphate soil				
Purakkad (Kerala)	245± 77	386± 60	High	Low

Source: Sekhon *et al.* (1992)

extracting these soils with 1N boiling HNO_3 (**Table 1**). Accordingly, when the information on both available as well as reserve K was studied together for making fertilizer K recommendations, the following picture emerged (Sekhon *et al.*, 1992):

Altogether, out of the 29 bench-mark soil series, 9 were low in both available and reserve K and should readily respond to K application. These soils occur in the districts of Anantnag (Kashmir), Gurgaon (Haryana), Puri (Orissa), Birbhum (W.B.), Nalgonda (A.P.), Bangalore, (Karnataka), Ratnagiri (Maharashtra) and Trivandrum (Kerala).

Two soils were moderate in available but low in reserve K. These need small applications of fertilizer K at present but should get depleted faster. Seven soils, mainly from U.P. and Bihar were moderate in available but high in reserve K. Such a situation suggests slow release of reserve K that needs small application of K. Four soils were high in both available and reserve K. These would not need K in the near future. Five Vertisols and Vertic type soils and two alluvial soils had high amounts of available but low amounts of reserve K. These soils could raise crops without fertilizer K for sometime but may soon get depleted. Shallow Vertisols (particularly from Madhya Pradesh and Gujarat states) are not self-fertilizing, hence may need fertilizer K application soon enough.

Similarly, soil series of West Bengal have been classified on the basis of their exchangeable and non-exchangeable K status and their need for K application (Sarkar *et al.,* 2001) (**Table 2**). Hanrgram soil series which was found to be moderate in available K earlier changed to low category in the later study under intensive cropping.

Available K in mineralogically different soils

Potassium availability is mostly dependant upon dominant as well as associated minerals in clay and silt fractions of soils. Twenty-two benchmark surface and sub-surface soils known to occur widely in intensively cultivated areas in 14 states of India have been studied for loosely-held and strongly-held forms of K in relation with clay mineralogy. The average amounts of K extracted by different extractants in these soil groups based on dominant clay mineral (**Fig 1**) indicated the gradual increase in the K extraction from water soluble K to NaTPB-K in the three mineral groups. Smectitic Vertisols and associated soils, with high clay content and with mica as an associated clay mineral and corresponding larger surface area and CEC, showed higher exchangeable forms of K and high K fixing capacity (**Fig. 2**) (Srinivasarao *et al.* 2000a). Illite or mica with larger interlayer K is the major source of slowly available K. Therefore NaTPB extracted higher amount of K from illitic soils

Table 2: Potassium Fertility status of Bench mark soil series from West Bengal

Agro-eco zone	*Available K status*	*Reserve K status*	*Expected need for K application*	*Soil series*
15.1	Low	Low	Will readily respond to K fertilization	Hanrgram, Konapura, Barakhardra, Kharbona
	Low	High	Need lower rates of K	Balidanga, Srirampur, Ghoshat, Deuli,
	High	Low	Can supports crops for sometime but may soon get depleted	Jagdishpur
	High	High	May not need K in near future	Banpara, Arapanch, Kanagarh
12.3	Low	Low	Will readily respond to K fertilization	Dakshinbahal, Jitujuri, Kusumasuli, Ranga
	Low	High	Need lower rates of K	Dayalpur
	High	High	May not need K in	Sirkabad, Bankathis
18.5	High	High	May not need K in near future	Patharpratima, Canning, Kakdwip
15.3	Low	High	Need lower rates of K	Mohitnagar

Source: Sarkar *et al.*, 2001

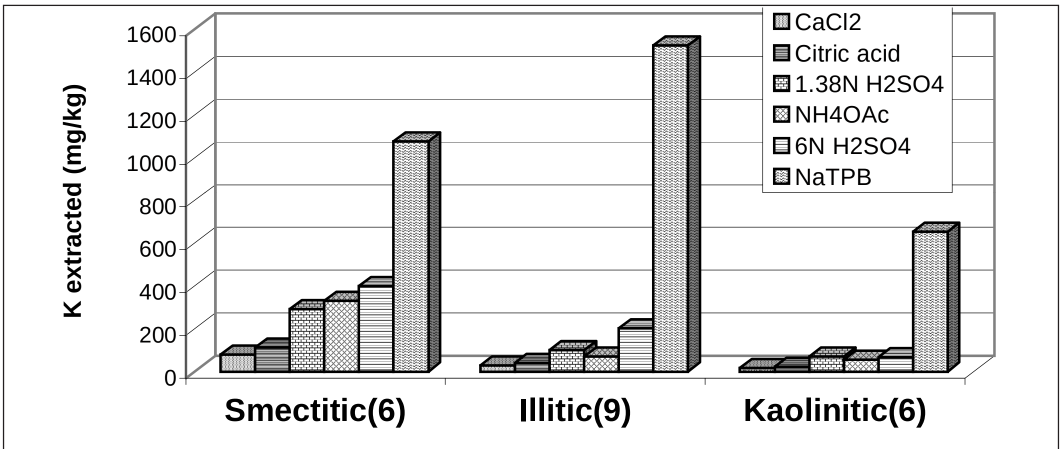

Figure 1. *Different forms of K in mineralogically different benchmark soil series. Source: Srinivasa Rao et al. (2000b)*

as compared to smectic soils. Kaolinitic soils with low CEC and clay content showed low levels of K in different extractants. Relative contribution of clay and illite to K replenishment capacity of soils under intensive cropping was reported for some illitic alluvial soils and smectitic soils of central India by Srinivasarao *et al.* (1998). Importance of silt mica in plant mobilization of soil

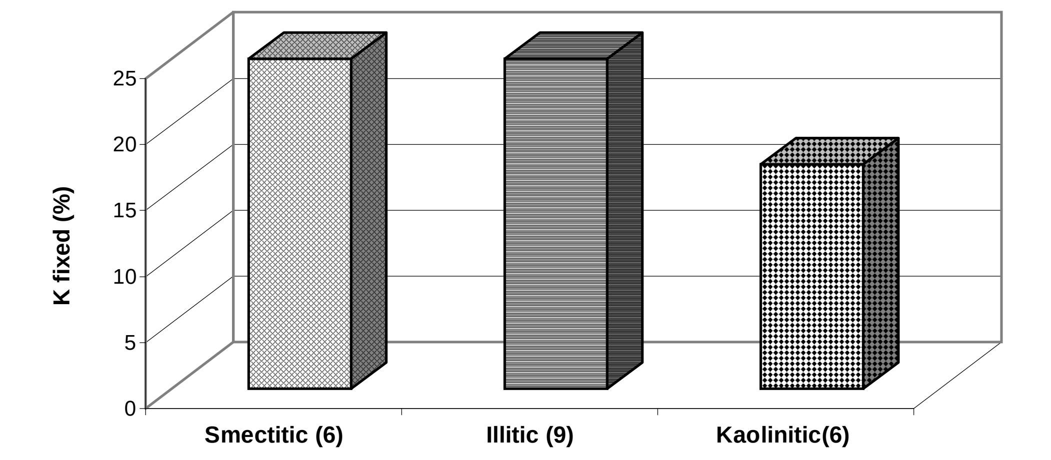

Figure 2. *Potassium fixation capacity of mineralogically different benchmark soil series in India. Source: Srinivasa Rao et al. (2000a)*

reserve K along with clay mica was reported by Srinivasarao *et al.* (2000b,).

Subsoil K fertility

Although a major portion of K is absorbed by crop plants from the surface soil, subsoil contribution to K nutrition is often substantial. The amount of K taken up from lower soil horizons depends on K concentration in soil and rooting characteristics of plant. Part of the plant nutrients applied on surface soil may leach down and accumulate in subsoil horizons that are often exploited by deep-rooted crops in a crop rotation. Different forms of K in subsoil (15-30 cm) were evaluated in relation to those in surface soil (0-15 cm) in 22 benchmark soil series of India (Srinivasarao *et al.*, 2001). The overall proportion of subsoil K to the surface soil K varied from 71 to 96, 62 to 90, and 60 to 82% in kaolinitic, illitic and smectitic soils, repectively.

Non-exchangeable K (NEK) Contribution

Potassium availability to crop plants is controlled by the dynamic equilibrium among different forms of soil K which facilitates the release of K from non-exchangeable form to available forms under K stress environment. A review of Mengel (1985) on uptake of K from non-exchangeable form indicated that many plants particularly the monocots feed on this source of K. Potassium fertility is characterized generally based on readily available K forms. However, many reports indicate the instances where available K based on

NH_4OAc extraction is not sensitive to the changes in soil K that take place during cropping. Therefore, recently a trend is emerging on characterization of soil K based on non-exchangeable K fraction in soil (Srinivasarao *et al.* 2001b). Twenty-nine benchmark soil series collected by Potash Research Institute of India have earlier been categorized based on non-exchageable K reserves as shown in **Table 1** (Sekhon *et al.*, 1992).

K releasing capacity of Indian soils

The pattern of successive extraction of nonexchangeable K from three mineralogically different soil series i.e., smectitic Noyyal, illitic Rarha and kaolinitic Kodad in different media of extraction indicated that the amounts of K released was generally higher on smectite dominant soils followed by illitic and kaolinite dominant soils. The amount of K extracted was greater in the first 3-4 extractions, decreased in later extractions and then maintained nearly same level after 10-11 extractions. Within each group there was a wide variation in the cumulative K release between soils which could be due to variations in clay content as well as associated minerals in silt and clay fraction of soil. Surface soils (0-15 cm) showed larger cumulative K release in smectitic and illitic soils as compared to the sub-surface (15-30 cm) soils irrespective of the media of extraction. In case of kaolinitic soils, surface soils showed either the same or lower K release than sub surface soils. This could be due to downward movement of finer particles with leaching during rainy seasons. Therefore, sub-soil K play an important role in case of kaolinitic soils which are generally low in K because of lower readily available K levels.

Studies conducted at PRII provided some interesting information on the K release as influenced by mineralogy in each group of soils containing similar NH_4OAc-K (Bansal et.al, 2001). In the 40 mg kg^{-1} NH_4OAc-K group, cumulative K release ranged between 64.1 mg kg^{-1} (0.164 cmol/kg soil) in Kumbhave (laterite) to 97.7 mg kg^{-1} (0.250 cmol/kg) soil in Balisahi (alluvial). In general, the alluvial soils had higher cumulative K release than red and laterite soils. This trend was also evident in soils having 80 and 200 mg kg^{-1} NH_4OAc-K (**Table 3**). The presence of illite in alluvial soils provided higher K release capacity than kaolinitic red and laterite soils. Among mineralogically different soils, the presence of major minerals strongly influenced the release of K. It was observed that though the soils may have similar mineralogical make-up, some other factors like clay/silt content, non-exchangeable K content and minor minerals also play an important role in influencing the K release from

Table 3. Amount of K released by 0.01 M $Cacl_2$ for soil having 40 ±, 80 ± and 200 ± mg K/kg soil ammonium acetate K

Soil group (NH_4OAc K mg K/kg)	*Soil Series*	*Mineralogy*		*Cumulative K released (cmol/kg soil)*	*Release Rate (cmol K^+ kg^{-1} Soil $hr^{-1}x10^{-3}$)*	
		Major (%)	*Minor (%)*		*External*	*Internal*
40 ±	Lukhi	Illite (36.7)	Chlorite (28.3)	0.243	2.38	0.67
	Vijayapura	Kaolinite (52)	Amorphous (17.9)	0.198	1.97	0.71
	Vijayapura	Kaolinite (52)	Amorphous (17.9)	0.230	2.00	0.70
	Nedumangad	Kaolinite (40)	Amorphous (20)	0.217	2.08	0.62
	Balisahi	Kaolinite (50)	Illite (20)	0.250	2.56	0.66
	Kharbona	Kaolinite (40)	Illite (30)	0.246	2.77	0.52
	Kharbona	Kaolinite (40)	Illite (30)	0.218	2.30	0.59
	Lidder	Kaolinite (55)	Illite (15)	0.219	2.21	0.59
	Khumbhave	Kaolinite (60)	Illite, Vermiculite(15)	0.169	1.25	0.54
	Tyamagondalu	Kaolinite (41)	Amorphous (17.9)	0.223	2.44	0.55
80 ±	Lukhi			0.299	3.56	0.67
	Lukhi			0.307	3.90	0.64
	Khatki	Illite (60)	Chlorite (15)	0.274	3.08	0.64
	Akbarpur	Illite (51)	Smectite, Chlorite(15)	0.296	3.49	0.67
	Nedumangad			0.333	5.00	0.49
	Vijayapura			0.293	4.10	0.51
	Vijayapura			0.288	3.97	0.51
	Kodad	Kaolinite (52)	Illite (15)	0.231	2.82	0.49
	Bagru	Illite (40)	Kaolinite (20)	0.277	3.49	0.57
	Kumbhave			0.217	2.43	0.50
200 ±	Akbarpur	Illite (51.3)	Smectite, Chlorite(10)	0.612	5.10	0.56
	Rarha	Illite (60)	Smectite (10)	0.677	5.64	0.32
	Pemberty	Smectite (31.7)	Illite (26.7)	0.590	4.59	0.78
	Hangram	Smectite (30)	Kaolinite (25)	0.519	4.85	1.19
	Masitawali	Illite (55)	Kaolinite (20)	0.592	5.28	1.08
	Sarol	Smectite (42)	Mixed layer (20)	0.425	2.90	1.67
	Kalathur	Smectite (45)	Kaolinite (20)	0.615	4.87	0.65

soils. Although, Kumbhave and Vijayapura were kaolinitic soils with 40 mg kg^{-1} NH_4OAc-K and similar non-exchangeable K content, there was a difference of 25 mg kg^{-1} between their cumulative K release. This might be due to the coating of silicate minerals by amorphous material present in the soil, which could hinder the release of K. In case of 80 mg kg^{-1} group, cumulative K release ranged between 83 mg kg^{-1} (0.217 cmol / kg soil) in Kumbhave (laterite) to 120 mg kg^{-1} (0.307 cmol / kg soil) in Lukhi (alluvial). For 200 mg kg^{-1} group, Rarha (alluvial) was followed by Kalathur (Vertisol) in terms of K release. Smectitic soils, in general, have a fast exchange rate and thus could release high amount of K. However, the presence of mica in alluvial soils gives them the power to release K in a more sustained manner over a long time than smectitic or kaolinite soils. This observation is important for nutrient management of agricultural soils of varying mineralogical make-up.

Plots of cumulative K released to $CaCl_2$ consisted of two parts, an initial non-linear part representing a rapid K release and second part representing a constant slower K release. The intercept of the linear part on the ordinate axis provides an estimate of amount of exchangeable K released from planer surfaces, edges and wedges zone (external K), while difference between cumulative K released and external K constituted the K release from the inter-lattice positions (internal K).

Cumulative K release from some of the bench-mark soil series indicated that the soils dominant in kaolinite mineral (Kumbhave, Tymangondalu) release K at slow rate whereas the Illite soils (Akbarpur, Khatki, Rarha, Masitawali) release more K and at a faster rate (Majumdar, 1999). Cumulative release from some vertisols has been shown in **Fig. 3**. The higher amount of external K in laterite soils (Nedumangad) occurred because of the larger planer external surface of kaolinite, the dominant clay mineral in these soils. It may be also due to removal or reorientation of Fe/Al hydroxy polymer in red soils after K adsorption, resulting in faster K-release giving larger amount of external K. A low magnitude of internal K from these soils was attributed again to dominant presence of kaolinite, which lacks the structural K. Micas are the dominant minerals in alluvial soils which contain tightly held inter layer K^+ ions and these are in equilibrium with surface K. Structural units in smectite are loosely held together, consequently ion and water molecules are able to penetrate into the inter layer spaces resulting in greater amount of internal K as in the case of Sarol, Hanrgram and Pemberty soil series.

Kinetics of K release

Various mathematical models have been used to describe the kinetics of K release from the various soil series. Among the three equations used to describe K release in soils, the power function model was found to be good in explaining potassium desorption from different soils as it recorded the highest value of 'r' and low value of 'SE' (Bansal *et al.*, 2001). The power function equation incorporates both the exchange reaction and diffusion controlled process, hence it is usually a better model to describe K release process in the soil. First order and parabolic diffusion equation did not prove suitable to

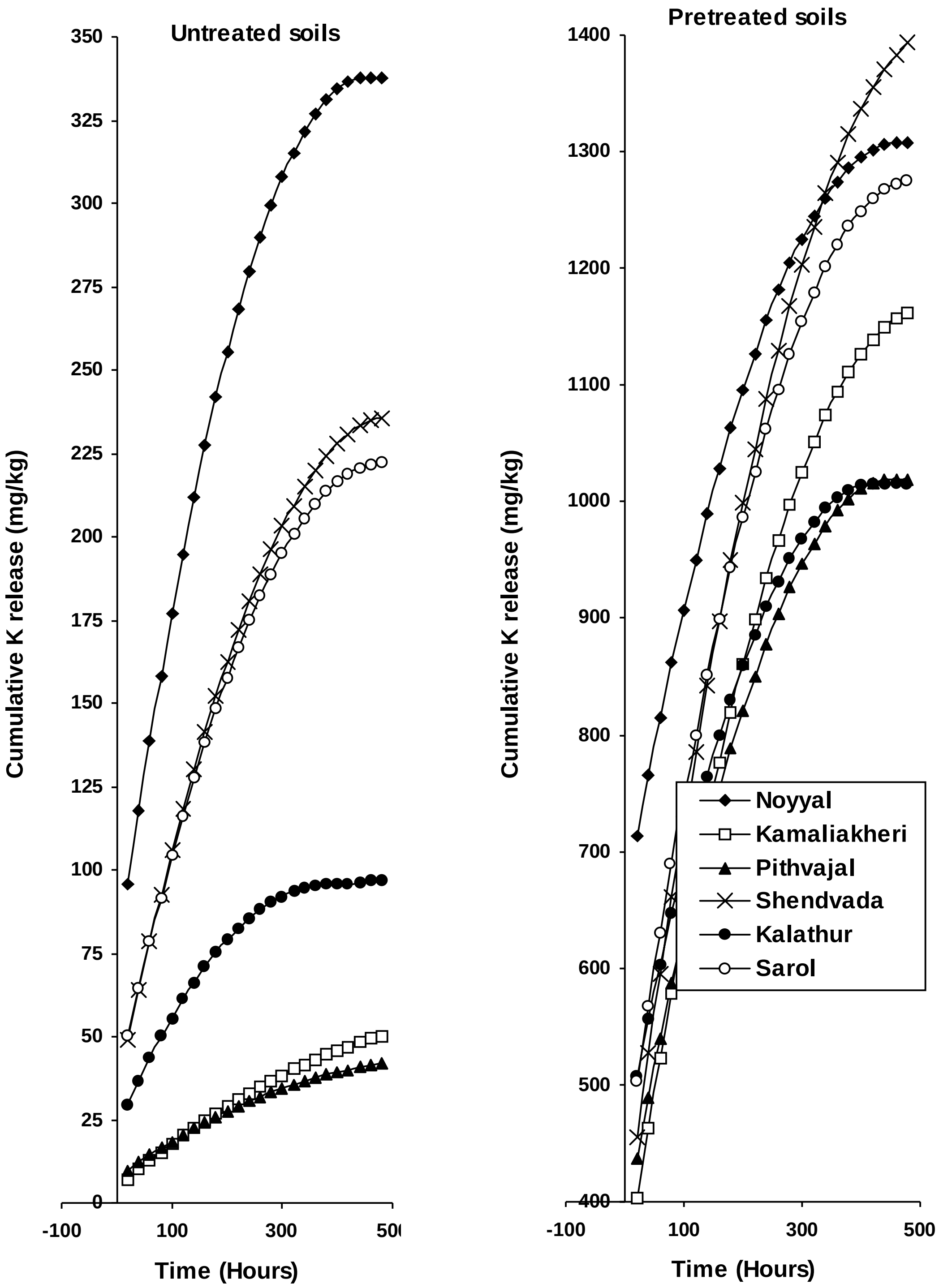

Figure 3: ***Cumulative K released to 0.01M $CaCl_2$ by untreated and pre-treated vertisols.***

describe the kinetics of potassium desorption which was evident from relatively lower ‘r’ and higher ‘SE’ values (**Table 4**). For 40 mg kg^{-1} samples, the first order (exchange process) and parabolic equation (diffusion controlled process) could not singularly describe the K release due to low potassium releasing capacity of minerals present in the selected samples, which improved considerable with increase in NH_4OAc- K content of the soils. So a combined equation like power function showed a much better fit. However, as the NH_4OAc-K content of soils increase, both exchange and diffusion controlled processes of K release become important. This is due to the fact that soils of high NH_4OAc-K content have either high illite (diffusion controlled release) or high smectite (exchange controlled release) content thus, first order or parabolic equation adequately describe the K release.

Table 4. Coefficient of determination (r^2) and standard error of estimate (SE) of various kinetic models for K release from 40, 80, 200 mg kg^{-1} soil samples

Models	*40 mg kg^{-1}*				*80 mg kg^{-1}*				*200 mg kg^{-1}*			
	r^2		*SE*		*r^2*		*SE*		*r^2*		*SE*	
	Range	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*
First order	0.53-0.70	0.57	0.03-0.10	0.07	0.38-0.59	0.47	0.08-0.19	0.12	0.72-0.83	0.79	0.03-0.05	0.04
Parabolic diffusion	0.63-0.80	0.72	0.02-0.07	0.05	0.55-0.75	0.64	0.05-0.11	0.07	0.87-0.97	0.91	0.01-0.03	0.02
Power function	0.93-0.99	0.95	0.06-0.19	0.13	0.90-0.98	0.94	0.12-0.33	0.22	0.93-0.99	0.95	0.09-0.12	0.12

Its quite clear that among the soils having similar NH_4OAc-K content, smectitic and kaolinitic soils will require higher application of potassium fertilizer than alluvial soils to sustain crop growth and increased productivity.

Decline in K fertility of Indian soils

Causes of soil K depletion

It is now firmly established that because of heavy withdrawals of nutrients from soil under multiple cropping systems with high yielding and fertilizer responsive varieties, the potassium status of soil is changing rapidly. It is of great importance to keep a close watch on such depletion of soil potassium through regular monitoring to ensure that potassium does not become a limiting factor in crop production and to commence its application in appropriate doses as soon as deficiency occurs. In the past, low yielding traditional varieties grown without or with only a little bit of nitrogen fertilizer did not put any particular stress on soil potassium. Hence, even soils, which are currently rated sufficient in available K may begin to show response to K with intensification of agriculture under extensive use of N and P fertilizers.

Changing scenario of crop response to applied K

The picture of crop response to K in India has been changing with time as more and more soils showed signs of K depletion as use of N and P without K progressively increased. When Vaidyanathan (1935) analyzed the results of experiments conducted in the country until 1930, he observed that cereals- rice, wheat, maize had a negative response, and potato and groundnut alone had substantial response. But until nineteen fifties, response to K in the presence of adequate supplies of other plant nutrients had not been adequately studied (Stewart, 1947)

Changes in K fertility of soils, and resultant increase in crop responses to K was first noticed by Mukherjee *et al.* (1955) while analyzing the results of a large number of simple trials on fertilizers in Bihar. All soils showed a positive response, although the magnitude of response differed from one district to another.

Recent reviews prepared on crop response to K in different soils India have indicated positive response to K application in most of the areas (Subbarao and Srinivasarao, 1996; Bansal and Umar, 1998; Bansal, 1999a and 1999b).

Depletion in soil K under Intensive cropping

In an exhaustive study with 17 heavy-black soils of West Godavari district of Andhra Pradesh, Venkatasubbiah *et al.* (1976) observed that the exchangeable potassium decreased from 328 to 96 mg/kg with a drop in mean potassium saturation from 1.64 to 0.47 per cent after sixth crop. Studies on response of maize crop to applied K on nineteen coarse textured soils in a green house experiment at PAU, Ludhiana indicated that on an average, maize cropping for seven years resulted in 61% depletion in available soil K from its initial status in control pots. On the other hand, K application resulted in an increase of 84% in available and 80% in water-soluble K over control pots. Cropping of 10 years caused significant depletion in soil K in some of the soil series from northern and eastern India, it did not bring about any change in the K fertility of five bench make soil series from southern India, though mean available K decreased by 15 mg to 21 mg / kg soil (**Table 5**) (Bansal *et al.*, 1996 and 2001). Reserve K did not show any significant change.

Chatterjee and Mandal (1996) while studying the potassium nutrition under intensive cropping in an Entisol of West Bengal, observed that any reduction in the recommended dose without compensating through organic matter / manure, resulted in depletion of soil available K at 0-15 cm soil depth. At 150% of the recommended dose, the available K status improved in 0-15 cm soil depth in rice-potato-sesame, rice-potato-mungbean and in 0-15 and 15-30 cm depth in rice-potato-groundnut systems. The non-exchangeable K in 0-15 cm soil depth of rice-potato-mungbean and rice-potato-groundnut was also reduced in all the treatments but the depletion was low whenever organic matter / manure or 150% recommended doses of K were added. Even the non-exchangeable K at 15-30 cm soil depth also got depleted similarly.

Effect of Soil Texture on Changes in Soil K

Changes in estimates of K by water soluble, NH_4OAc and HNO_3 extractable K as per textural classes in the 10 soil series was studied by Bansal (2000) and are presented in **Table 6**. Among the different textural classes in the same soil series, it was observed that finer textured samples, generally contained more amounts of different forms of K. Effect of texture on different forms of K was seen prominently in available and reserve K of Lukhi, available K in Nabha, available and reserve K in Akbarpur, Vijayapura, Kodad and Noyyal soil series. Both NH_4OAc-K and HNO_3 extractable K increased with heaviness of texture in these series.

In general, there was an increase in water soluble K with time in all textural classes of Rarha, Kodad, Noyyal and Kalathur soil series possibly due to the slight shifting of equilibrium (soil solution K $\leftrightharpoons$ exchangeable K $\leftrightharpoons$ non-exchangeable K) towards the left as cropping enhanced the release of K. Generally, reserve K decreased with time in all the textural classes of all the soil series with some exceptions and the magnitude of decrease varied with texture to some extent only. It could perhaps be inferred that depletion of K with cropping in the same soil series is less with increase in heaviness of the soil texture. This is because more amounts of silt and clay mean the presence of more amount of K in the soil and more dynamic is the K exchange equilibrium in the soil.

Table 5. Potassium Fertility with Cropping over Time

Soil series	*NH_4OAc-K (mg/kg ± SD)*				*HNO_3-K (mg/kg ± SD)*			
	Earlier	*After 10 years*	*Change*	*CD*	*Earlier*	*After 10 years*	*Change*	*CD*
a) Alluvial								
Nabha (Punjab)	104± 54	60 ± 47	–44	21	965 ± 255	875 ± 230	–90	77
Lukhi (Haryana)	78± 45	65 ± 34	–13	NS	618 ± 159	533 ± 173	–85	65
Akbarpur (U.P.)	125± 41	71 ± 23	–54	29	1448±203	1231±188	–217	89
Rarha (U.P.)	95±33	79±20	–16	NS	1531±353	1497±180	–34	NS
Khatki (U.P.)	99± 22	95±55	–4	NS	1494±212	1454±222	–40	NS
Bagru (H.P.)	94± 37	90 ± 37	–4	NS	346±64	322±104	–24	NS
Balisahi (Orissa)	30± 14	37 ± 18	+7	NS	92±34	81±50	–11	NS
Jagdishpur Bagha (Bihar)	79± 58	77 ± 61	–2	NS	1753±220	1749±201	–4	NS
Raghopur (Bihar)	89± 29	94 ± 46	+5	NS	2115±408	2219±326	+5	NS
Hanrgram (W.B.)	132± 53	93± 16	–39	28	425±160	400±191	–25	NS
Kharbona (W.B.)	42± 17	29± 16	–13	NS	119±34	109±26	–10	NS
Chandole (A.P.)	424± 233	406± 265	–18	NS	1030±565	1018±466	–12	NS
b) Red								
Kodad (A.P.)	70± 32	67 ± 39	–3	NS	266 ± 70	256 ± 95	–10	NS
Vijayapura (Karnataka)	68± 43	43 ± 15	–25	16	127 ± 57	121 ± 34	–6	NS
Tyamagondalu (Karnataka)	76± 27	77 ± 18	+1	NS	365 ± 12	388 ± 128	+23	18
Doddabhavi (Tamil Nadu)	92± 31	92± 34	0	NS	1049 ± 239	998± 341	–51	48
c) Black								
Noyyal	688 ± 132	673 ± 120	–15	NS	2339±276	2320±195	–19	NS
Kalathur	193± 38	172± 46	–21	20	893 ± 102	934 ± 140	+31	NS

Effect of Cropping Systems on changes in Soil K

Changes in available and reserve K status of different fields from 10 bench mark soil series under different cropping systems were studied by Bansal *et al.* (2001) and are given in **Table 7**.

The results indicated that in Lukhi soils, receiving no K from outside, the K forms decreased and the magnitude of decrease depended upon the cropping system followed. In Nabha series, both available and reserve K decreased substantially under rice-wheat system receiving only 20 kg K_2O/ha/year external K application. After 10 years of cropping with maize-potato-wheat

Table 6. Changes in mean K extracted by water, NH_4OAc and HNO_3 according to textural classes in selected samples from 10 soil series over a period of time

Soil series	*Textural class*	*No. of samples*	*Mean K extracted (mg/kg) by*					
			Water		*NH_4OAc*		*HNO_3*	
			**I*	**II*	*I*	*II*	*I*	*II*
Alluvial								
Nabha	Sandy	7	29.5	27.6	80	48	690	668
	Loamy sand	14	41.2	27.6	142	61	1044	998
	Sandy loam	4	27.0	32.5	108	72	1335	975
Lukhi	Sandy	13	24.7	12.2	86	64	461	438
	Loamy sand	11	16.9	10.2	78	73	588	582
Khatki	Sandy loam	2	17.6	16.0	86	95	1425	1475
	Loam	14	15.5	12.0	95	79	1476	1393
	Silty loam	7	12.8	13.6	90	92	1450	1507
Akbarpur	Loamy sand	11	23.7	17.6	115	93	1505	1239
	Sandy loam	7	24.5	19.7	157	144	1324	1260
	Loam	5	26.8	25.4	165	158	1688	1474
Rarha	Loamy sand	9	15.0	18.8	79	83	1590	1433
	Loam	9	13.4	16.5	85	79	1559	1517
	Silty loam	6	19.5	13.5	115	72	1629	1438
Red								
Kodad	Sandy loam	8	9.3	12.0	46	71	245	231
	Sandy clay loam	8	12.6	12.9	82	93	291	268
Vijayapura	Sandy loam	11	15.9	11.2	49	38	120	124
	Sandy clay loam	11	16.5	13.4	65	62	146	147
Tyamagondalu	Loamy sand	7	19.6	18.7	55	47	320	309
	Sandy loam	14	20.5	20.2	83	86	359	367
Noyyal	Clay loam	3	77.5	85.5	658	683	2285	2233
	Silty clay loam	3	88.3	110	939	954	2475	2450
	Clay	5	91.3	81.2	702	750	2559	2590
Kalathur	Clay	3	13.2	26.5	212	168	833	810
	Clay loam	19	10.7	20.6	190	172	905	891

*I – Initial
*II – After 10 years cropping

crop rotation and receiving on an average of 95 kg K_2O/ha/year, the forms of K in Rarha soils also decreased substantially. However, with the maize-wheat/potato rotation receiving 60 kg K_2O/ha/year, the K status of soils remained more or less unchanged. In Khatki series, no change in K status of soils was observed with sugarcane-wheat crop rotation with an application of 25 kg K_2O/ha/year. However, a considerable decline was observed in both

Table 7: Changes in mean K extracted by NH_4OAc and HNO_3 according to cropping patterns in some of the soil series over a period of time

Soil series	*Cropping pattern*	*No. of fields*	*K_2O added (kg/ha/ year)*	*Mean K extracted (mg/kg) by*			
				NH_4OAc		*HNO_3*	
				**I*	**II*	*I*	*II*
Alluvial							
Nabha	Rice-Wheat	17	20	108	87	1054	981
	Cotton-Wheat	7	14	75	64	897	832
Lukhi	Bajra-Wheat / Barley	15	–	75	65	517	494
	Guar-Wheat	5	–	98	70	490	425
	Bajra-Gram	2	–	84	76	610	539
Khatki	Sugarcane-Wheat	16	25	89	90	1452	1462
	Maize-Wheat	9	–	95	69	1421	1352
Rarha	Maize-Potato-Wheat	17	95	98	77	1599	1464
	Maize-Wheat-Potato	7	60	85	85	1451	1462
Red							
Kodad	Rice-Rice	13	36	63	52	248	241
	Rice-Fallow	12	20	78	82	275	283
Black							
Noyyal	Sorghum-Fallow	11	18	702	709	2419	2434
	Sorghum-Sorghum	8	32	691	684	2332	2311
	Sorghum-Sugarcane	2	56	643	621	2381	2366
Kalathur	Rice-Rice	15	42	191	177	837	810
	Rice-Sugarcane	3	80	184	169	892	867
	Sorghum-Rice	2	34	178	181	966	959
	Sorghum-Rice / Moong	4	34	199	183	907	928

*I – Initial
*II – After 10 years cropping

the K forms with maize-wheat rotation receiving no K fertilization. An appreciable decrease in available K was also observed in rice based cropping systems in both Kodad and Kalathur soil series in spite of average annual additions of 36 and 42 kg K_2O / ha, respectively. This is because the K additions may be insufficient to meet the heavy removal of K in rice-rice system. However, there was no change in available K in the rice-fallow cropping system in Kodad series.

After 8-11 years of continuous cropping, available potassium in soils declined under most of the long term fertilizer experiments where potassium was not applied (Nambiar and Ghosh, 1984). In plots receiving N and P, the drop in available K was faster in the initial years than in the later years.

However, available K in soils improved by three K-fertility management programs: at 6 sites by addition of 50% of optimum K; at 7 out of 11 sites with optimal K application and at 8 out of 11 sites with 1.5 times of optimal K application. In the alluvial soils, a consistent build up was observed with increasing rates of K application, but not in the black and red soils. De Datta and Gomez (1975) found that after 8 years of intensive cropping, the exchangeable K dropped from 178 to 51 mg K/kg. In the absence of K, responses of both N and P also declined and in an unresponsive soil, crop responses to K started as crops removed much more K than applied through fertilizers.

Nambiar (1994) reviewed the results of the long-term fertilizer experiments from 1971-1987 and observed that at optimal (100%) to super optimal (150%) N P K doses, an appreciable improvement in available soil-K, amounting to 32-38%; 41-46% and 49-68%, respectively, at Ludhiana, Barrackpore and Delhi, took place. However, available soil-K declined in the absence of K application over 15-16 years. Maximum depletion in soil K took place in the NP treated plots due to the increased uptake of K. A declining trend in available K even at super optimal (150%) was observed on a Vertic-ustochrept soil at Coimbatore.

Fertilizer K application considerably reduced the contribution of native K to crop uptake (Ganeshmurthy *et al.,* 1985). However, in absence of K application, soil reserve K becomes major source of K for crop K needs. The change in different forms of K in relation to crop K uptake during 20 years of cropping on Inceptisol at Hyderabad, indicated the major contribution of soil reserve K in crop K uptake (Srinivasarao *et al.,* 2000c). Balance-sheet of K computed by Bansal (2000) after 13 crop cycles of sorghum-wheat in a long term fertilizer experient on an inceptisol at Gurgaon, indicated non-exchangeable contribution of more than 80% to the total K removed by the crops when no K fertilizer was applied (**Table 8**). The non-exchangeable K contribution was more to K uptake by crops in plots receiving no K, 88.8% in N_{120} P_{60} K_0 and 82.9% in N_{240} P_{120} K_0. It was comparatively lower in N_{120} P_{60} K_{60} (32.9%) and N_{120} P_{60} K_{60} + FYM (25.9%). Contribution of non-exchangeable K was about 102 kg/ha/year in the absence of K addition in N_{240} P_{120} K_0 and about 115 kg/ha/year when high rates of N and P were applied without K (N_{240} P_{120} K_0). Soil K balance was negative even with optimum K application. Only application of K at high rates of 120 kg/ha to each crop in N_{120} P_{60} K_{120} and (N_{240} P_{120} K_{120}).was able to maintain the positive balance of K in soil.

Table8 : Balance sheet of K (kg/ha) after 13 crop cycles in the long term fertilizer experiment on an Inceptisol

Treatments (kg/ha)	Total changes in available K in both depths					K added through fertilizers	K removal by crops	Contribution of non-exch. K
	1985-86 (I)		1997-98 (II)		(III) = (I - II)	(kg/ha)		
	0-15	15-30	0-15	15-30		(IV)	(V)	(VI=V+III-V)
$N_{120}P_{60}K_0$	157	160	83	80	-154	0	1375	1221 (88.8%)
N_{120} P_{60} K_{60}	168	168	136	91	-109	1075	1767	583 (32.9%)
$N_{120}P_{60}K_{60}$ + FYM	155	166	156	122	-43	1459	2056	554 (26.0%)
N_{120} P_{60} K_{120}	168	150	194	148	+24	2150	1832	+296
$N_{240}P_{120}K_0$	162	152	73	64	-187	0	1570	1384 (83.0%)
$N_{240}P_{120}K_{120}$	157	143	183	69	-48	2150	2006	+192
CD at 5%	9	8	21	11				

Figures in parentheses are the per cent contribution of non-exchangeable K to the K removals by the crops

Changes in K release rates under long term cropping

The release of non-exchangeable K (NEK) depends upon a number of factors such as nature and amount of clay minerals, level of exchangeable pool of K and the K reserves, addition of K fertilizers, cropping intensity, crop species and its root extension, root C.E.C., crop rotations, etc. Memon *et al.* (1988) suggested that initially K uptake by plants is solely from the exchangeable sources, but once the critical depletion stage has been reached, K uptake was chiefly from non-exchangeable fraction, with only a small further contribution from exchangeable sources. A fraction of NEK, which is held around the edges and wedge zones of micaceous minerals, is termed as "intermediate K" (Beckett, 1971). The latter may not ordinarily be extracted with neutral normal NH_4OAc, and is thus excluded while rating the K-fertility status of soils, but gets released when K concentration in soil solution upon depletion (by crop uptake, leaching, etc.) reaches a certain critical low value. The latter is known as the 'threshold' K level (Scott and Smith, 1966). The uptake of NEK by crop under exhaustive cropping in pot experiments (Richards and Bates, 1988; Pati Ram and Prasad, 1991) established the long-term K-supplying power of soil. This 'threshold' K level, for release of intermediate K, was independent of the amount of K reserve but depends rather on the nature of K-bearing minerals in soils (Song and Huang, 1983), and the clay structure as well as its degree of expansion (Datta and Sastry, 1988). The threshold level may not have fixed values for soils, subjected to long-term cultivation with intensity, without extraneous application of K fertilizers. A higher threshold value indicates less tenacity with which K is held in wedge zones of micaceous minerals (Datta and Sastry, 1988).

Changes in non-exchangeable K and exchangeable K relations with time

The relationship between exchangeable K content in soils, initially as well as after 10 years of cropping, and their corresponding non-exchangeable K content in some of the bench mark soils was studied by Bansal *et al.* (2001). The regression equations were computed and the correlation coefficients were also obtained. The changes in relationships between exchangeable K versus non-exchangeable K in mineralogically different soils, alluvial soils-illite dominant; red soils-kaolinite dominant and black soils-smectite dominant; have been depicted in **Figure 4**.

The correlation coefficients between non-exchangeable K and exchangeable K in the three groups of soils were significant and positive indicating a dynamic equilibrium between the two forms in these soils. The regression coefficients and slope values indicate the proportion of non-exchangeable K that becomes exchangeable. The slope value increased as the proportion of 2 : 1 expanding lattice minerals increased in the soils grouped according to mineralogy. Alluvial soils, which are illite dominant and have K specific and non-expanding 2 : 1 type of clay minerals, recorded the lowest value of slope indicating the lowest amount of exchangeable K per unit of the non-exchangeable K. This means that readily available exchangeable K as a proportion of non-exchangeable K is thus more in smectite-dominant black soils compared to the kaolinite-dominant red soils and illite-dominant alluvial soils. The lower values of correlation coefficients in alluvial soils also indicated that the release of K from non-exchangeable form to exchangeable form may be slow in these soils as compared to the other soils.

There was hardly any appreciable change observed in slope values after 10 years of cropping. The trend of change was also divergent as the regression coefficient values or slope values decreased in smectitic and illitic soils while it increased in the kaolinite – dominant red soils. This indicated that proportion

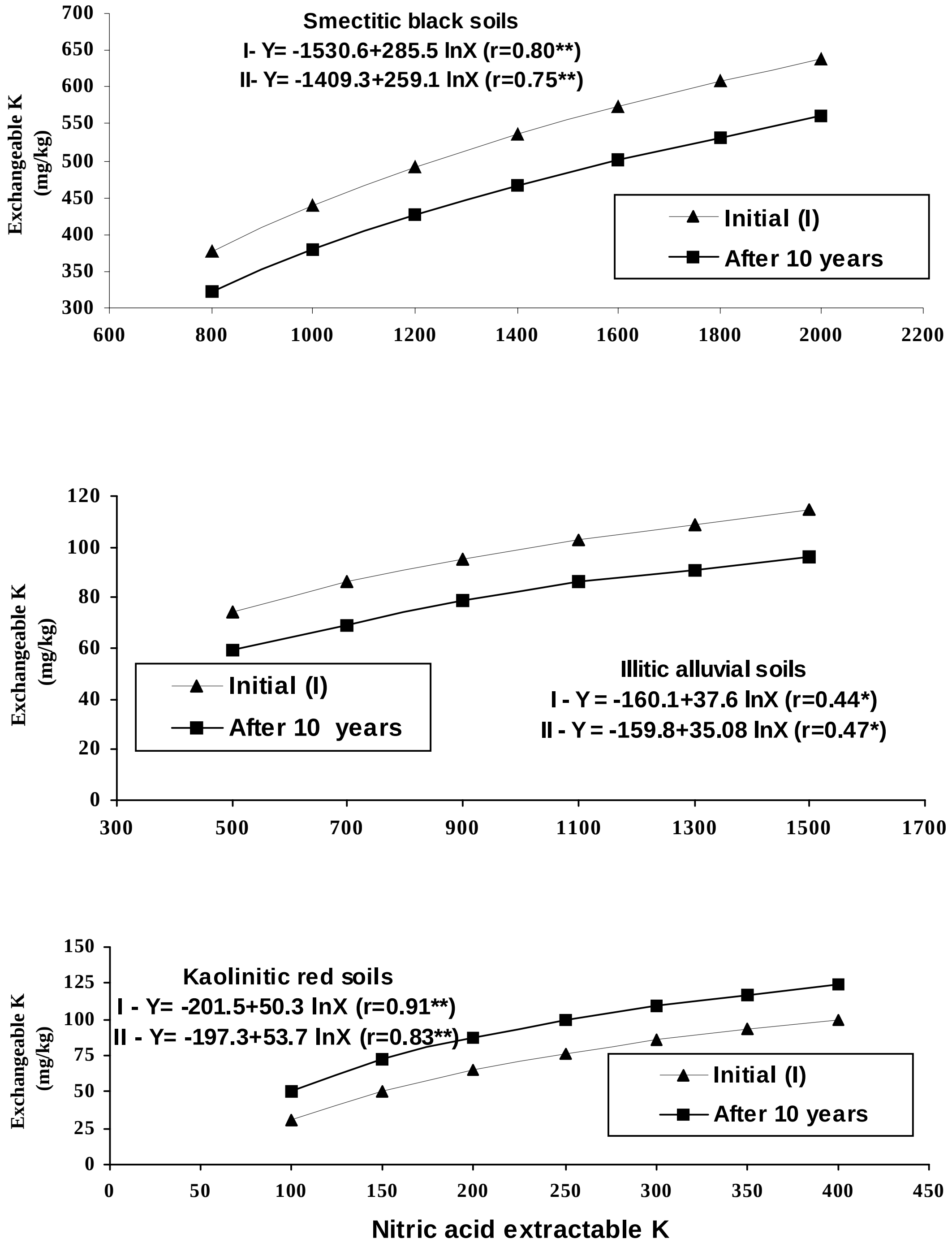

Figure 4. ***Effect of cultivation on relationship between HNO_3-extractable and exchangeable K content for different soil groups***

of non-exchangeable K that becomes exchangeable decreased in the alluvial and black soils while it increased in the red soils after 10 years of cropping.

Changes in K desorbed by EUF

In routine soil testing practices, K extracted by neutral normal NH_4OAc is used exclusively as a laboratory index of K availability. Nemeth (1979) had suggested use of electro-ultra filtration (EUF) to extract seven successive fractions of soil K, using different voltages and temperatures over a 35 minutes period. Bansal (2000) studied the cumulative K desorption with time and the plots for different soil series before and after the cultivation are depicted in **Figure 5**.

Amount of water soluble K in soils is generally comparable to the EUF-10 fraction initially as well as after the cropping. In the illite dominant 5 alluvial soils, generally water soluble K was higher than the EUF-10, but the reverse trend was obtained for kaolinite dominant red soils and smectite dominant black soils. Alluvial soils showed slightly lower values of EUF-10 K than of water soluble K probably due to the presence of illitic minerals, which have more affinity for K than smectite and kaolinite minerals. Water soluble K was relatively high in smectite dominant Noyyal and kaolinitic Tyamagondalu soils.

EUF-30, the cumulative K release in first six fractions (0-30 min) was less than even the NH_4OAc extractable K and it was roughly half of the NH_4OAc-K. In alluvial soils, the mean EUF- was reported not to show any appreciable change with cropping except in Akbarpur soil series, where it decreased form 61 to 49.1 mg/kg. In kaolinitic red soils and smectitic black soils, after 10 years of cropping, it indicated no significant change. However in the red soils, significant change was observed in the mean EUF K- quotient (EUF 30-35/EUF 30) values. The mean EUF - K quotient values were comparatively lower in the kaolinitic red soils.

The EUF K quotient (EUF 30-35/EUF 30) estimates the preponderance of differently extracted K, and is therefore considered a measure of buffering power (Sekhon *et al.*, 1992). This quotient is generally higher in illite and smectite dominant soils than in kaolinite-dominant soils. However, when the more easily extractable fractions are large, the quotient may turn out to be low. Thus, in some soils such as Nabha (illitic) and Noyyal (smectitic) soil

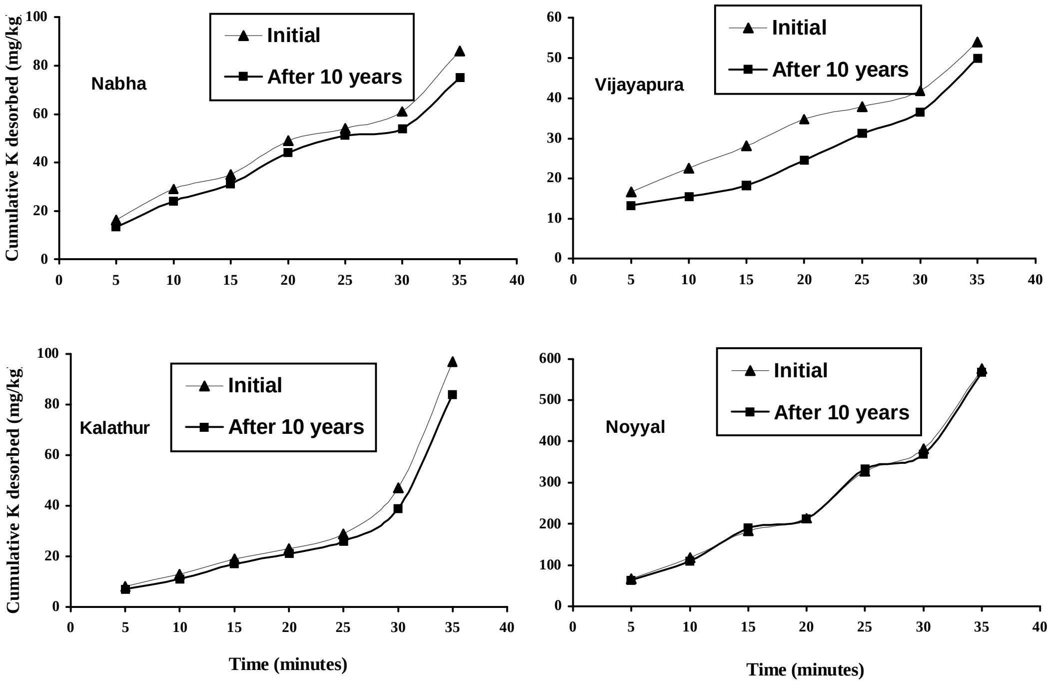

Figure 5: *Effect of cultivation on cumulative K desorbed by elctro-ultra filtration in Nabha (alluvial), Vijayapura (red), Kalathur (Vertic type) and Noyyal (Vertisol) soil series.*

series, buffering capacity was underestimated because of the larger amount of soluble and weekly bound K (EUF-30) in these soil series (Sekhon *et al.*, 1992). No change in the K buffering power of soils was observed with continuous cropping except in the kaolinitic red soils as they got comparatively more depleted of their easily extractable fractions of K with cropping.

Conclusions

- Based on K fertility evaluation of 109 benchmark soils of India, 17.5 per cent were low, 40 per cent were medium and rest were high.
- Out of 29 benchmark soil series studied critically for K fertility at PRII, Guragon, about 30 per cent soil series were marginal.
- Light textured red, lateritic and alluvial soils, acidic alluvial and shallow black soils are prone to K deficiency under intensive cropping.
- Dominant as well as associated minerals in clay and silt fraction of soils

mostly contribute to variations in K fertility of Indian soils.

- Though soils of alluvial belt of northern India are rich in nonexchangeable K, the release of K is very slow and K additions are essential at sensitive growth stages in particularly K loving crops.
- The magnitude of crop response has been on upward trend in many areas as a consequence of K fertility decline in these regions.

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