Impact of Long-Term Intensive Cropping on Soil Potassium and Sustainability of Crop Production

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Abstract

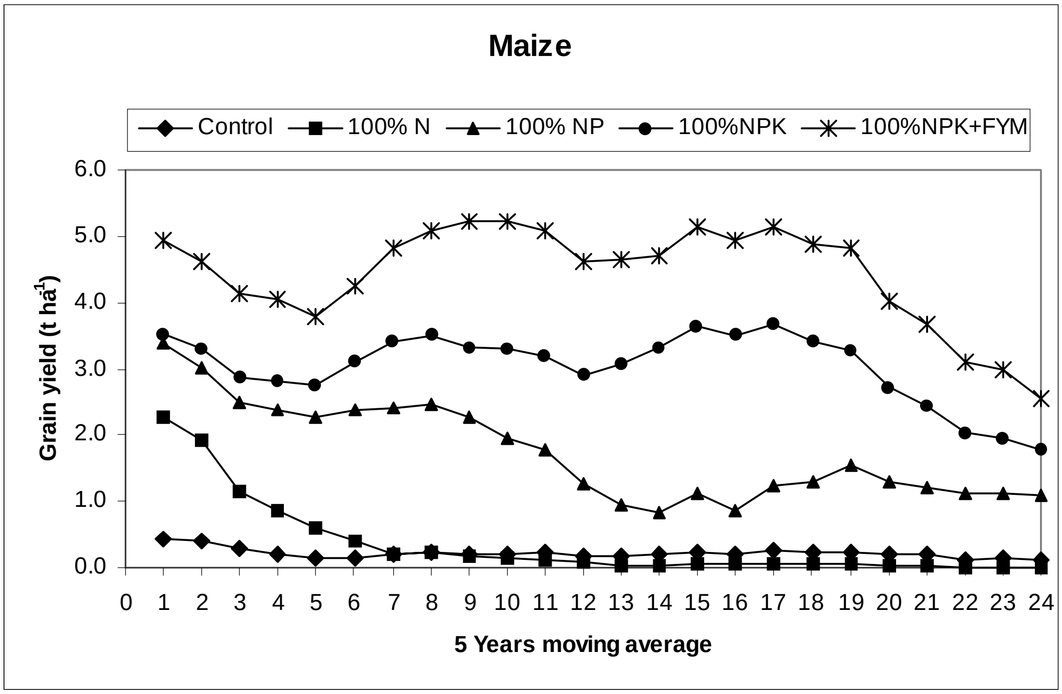
Fertilizer use in India is highly unbalanced especially with respect to potassium (K). Long-term fertilizer experiments conducted over 30 years in different agro-ecological regions involving diversified cropping systems and soil types showed significant responses of crops to K applications, the effects being more pronounced in Alfisols and acidic Inceptisols (Aeric Haplaquept). After several years of intensive cropping, response to K application occurred even in alluvial soils dominated by K bearing minerals (illite). Application of K enhanced its available status in soils and uptake by the crops. Contribution of the non-exchangeable K towards total potassium removal was above 90% in the absence of applied K which decreased to about 80% with the use of K. Studies on K release kinetics and Q/I parameters showed that cumulative K release was higher in K treated soils as compared to untreated ones thereby causing a greater decline in non exchangeable K reserves. The results suggest that in years ahead K will be the most limiting factor affecting sustainability of intensive cropping systems in India. Therefore, due attention must be paid to K nutrition in fertilizer scheduling for different crops/cropping systems.

Introduction

In most of the intensive cropping systems in India, potassium (K) balance is negative since the additions of K seldom match the K removals resulting in larger dependence on soil K supply. Under such conditions there is greater pressure on non-exchangeable K for meeting the K requirement of crops. Long-term intensive cropping, in the absence of K inputs, adversely affected the K supply to crop plants and consequently crop yields (Swarup, 1998; Swarup and Ganeshmurthy, 1998). Potassium deficiencies are now more widespread even on heavy textured soils such as alluvial illitic soils in India. Several studies have shown substantial contribution of non-exchangeable K towards K nutrition of crops grown on illite dominant alluvial soils (Srinivasa Rao *et al.*, 2001; Swarup and Chhillar, 1986). This is particularly so when cropping continues with N + P application without K addition. The K release rates from soils under long-term cropping, fertilization and manuring helps to predict the fate of added K in soil as well as nature of K supply from soil to plant K nutrition. This paper critically reviews the work done on soil potassium and its impact on the sustainability of crop production under the All India Coordinated Research Project of ICAR on Long-term Fertilizer Experiments.

Crop responses and K uptake vis-à-vis sustainability issues

It is generally considered that most of the Indian soils are adequate in K supply. Cereals especially those with deep rooting system often fail to respond to K in seasonal/short term field trials. The immediate conclusion drawn could be that no K is required for such cereals at these locations. However, the situation changes when intensive cropping is followed over the years on the same site with N + P fertilizer alone because with consecutive exhaustion the true response to K becomes obvious. For example, the crops under long-term experiments on a Mollisol soil at Pantnagar (Nand Ram, 1998) and Vertisol soil at Jabalpur (Tembhare *et al.*, 1998) responded to K only after few years of cropping because of its good spatial K exploitation whereas trend in yield declines occurred from the beginning in Alfisols at Bangalore , Ranchi and Palampur and in an Inceptisol (Aeric Haplaquept) at Bhubaneswar (**Figs. 1 to 4, Table 1**). Even in K rich alluvial soil (Typic Ustocrept) at Ludhiana, maize and wheat responded to K application from the very beginning (Brar and Pasricha, 1998). A comparison of mean response of K (NPK over NP) showed that yield responses to N and P fertilizer declined in all the soils, the effects being more pronounced in Alfisols and more so at Bangalore under finger millet-maize cropping system (**Table 1**). On the contrary, a declining trend in response to K fertilizer was observed in maize at Ludhiana and rice at Pantnagar after about 10 years of continuous cropping. It was found to be associated with the emergence of Zn deficiency. Thus it can be inferred that the real response to K fertilization can be fully realised only when all the limiting plant nutrients (secondary and micronutrients) are present in optimal amounts in the soil (**Table 2**). The K uptake by crops even at 100% optimal NPK dose was far in excess of the fertilizer K applied to the crops on almost



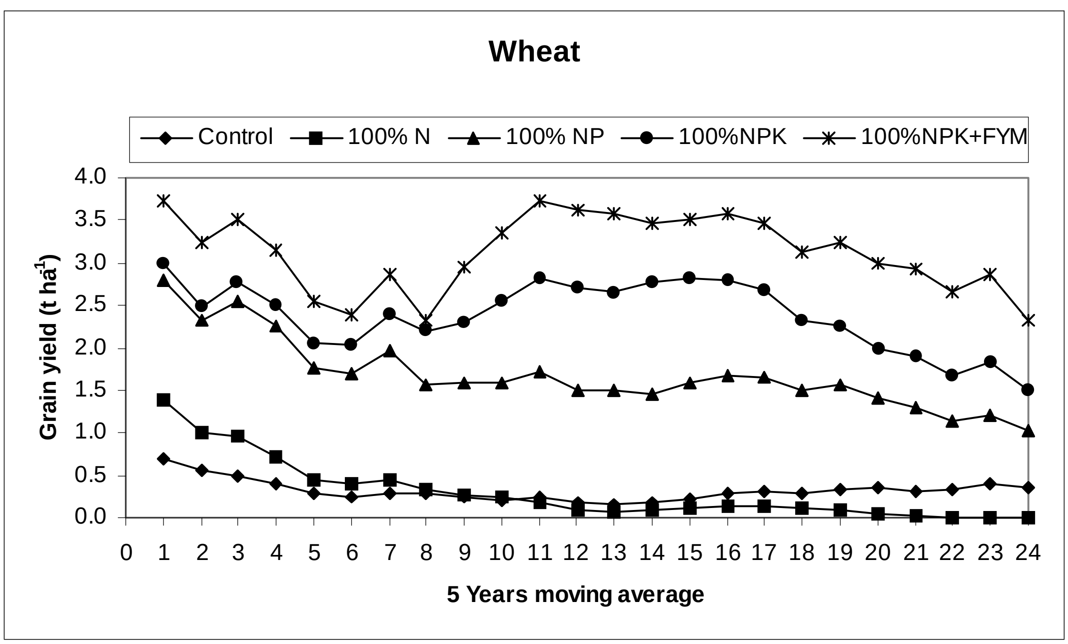
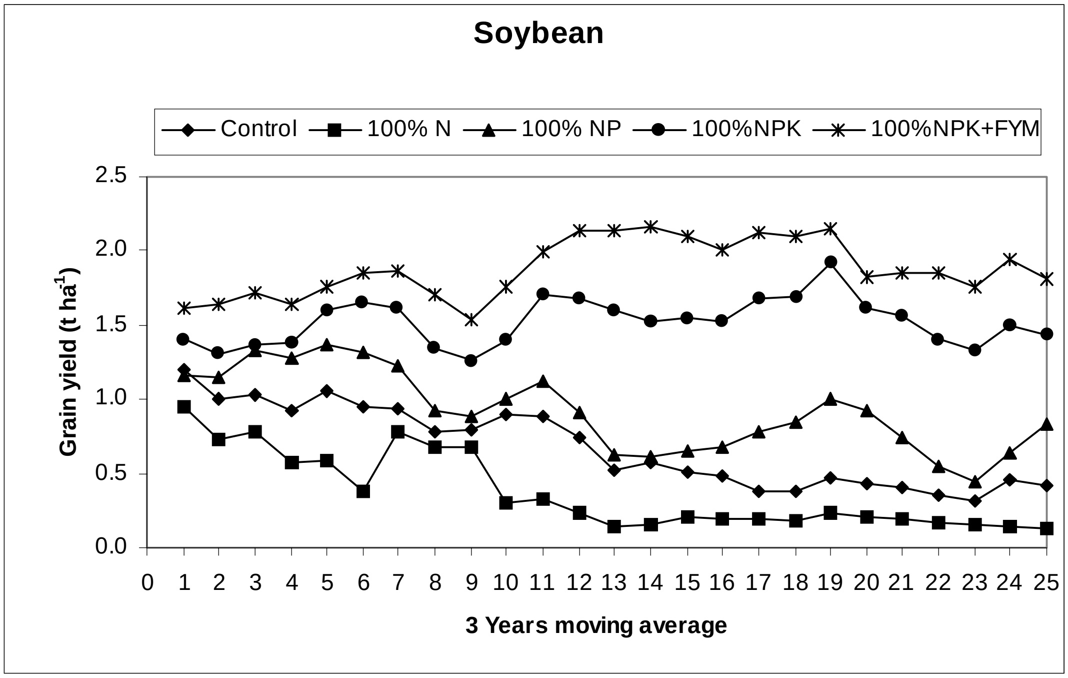


Fig. 1. *Effect of different fertilizer treatments on grain yield of Maize and Wheat at Palampur*



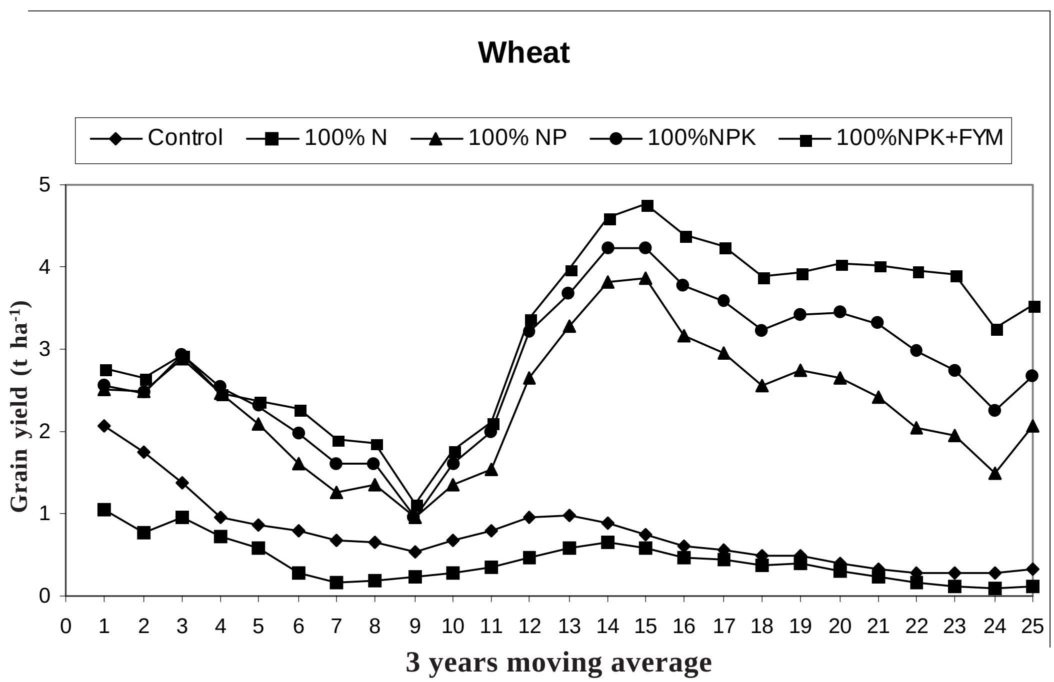
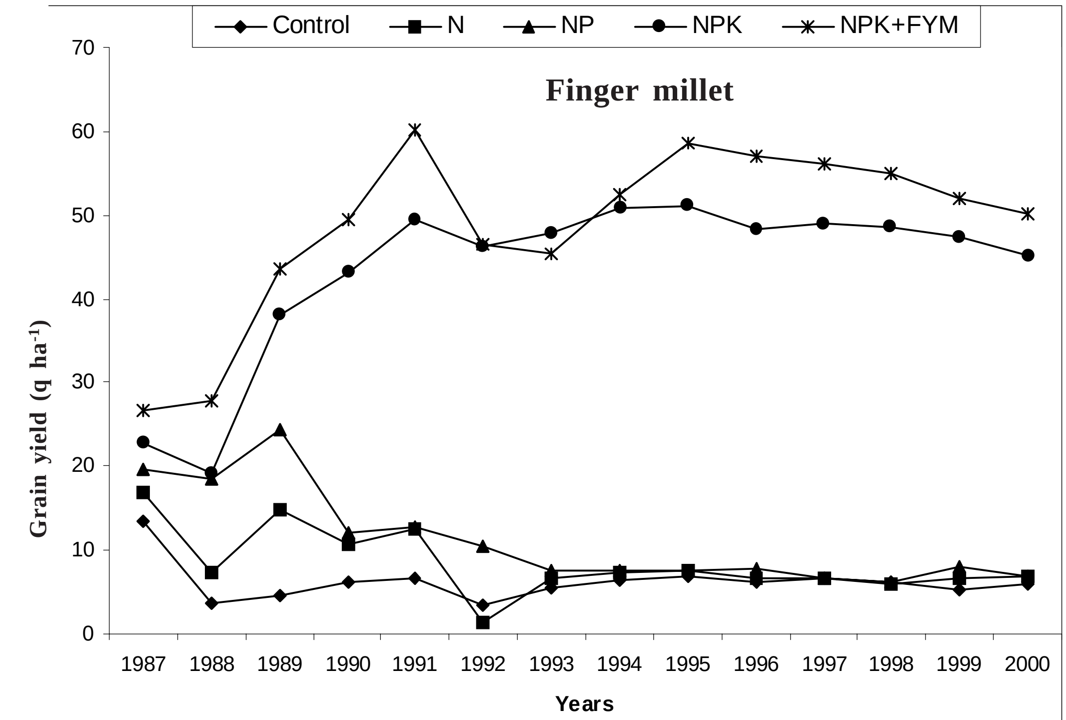


Fig. 2. *Effect of different fertilizer treatments on grain yield of soybean and wheat at Ranchi*



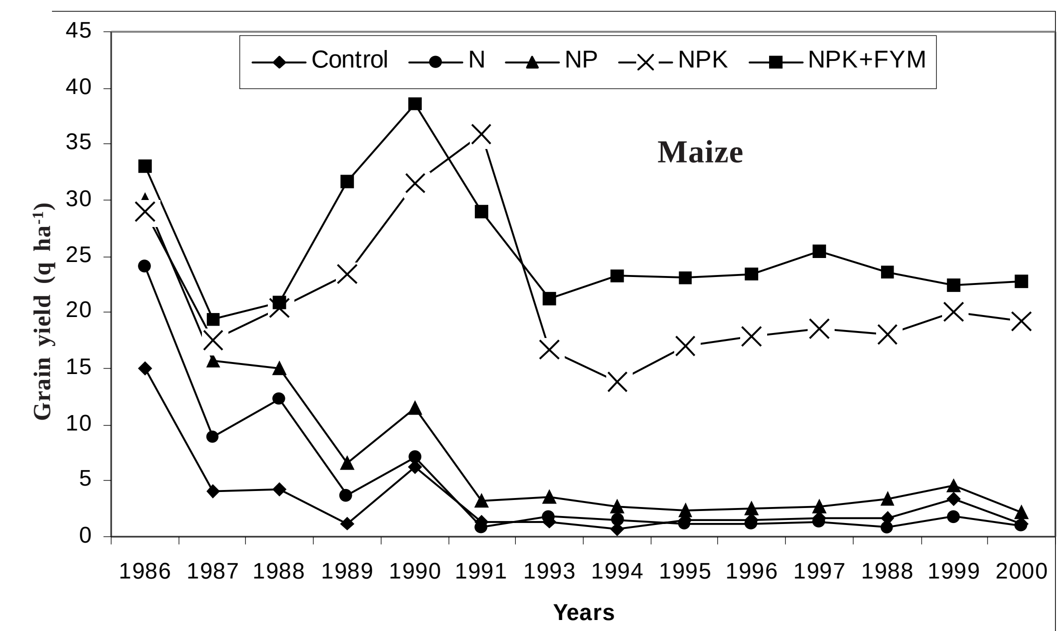
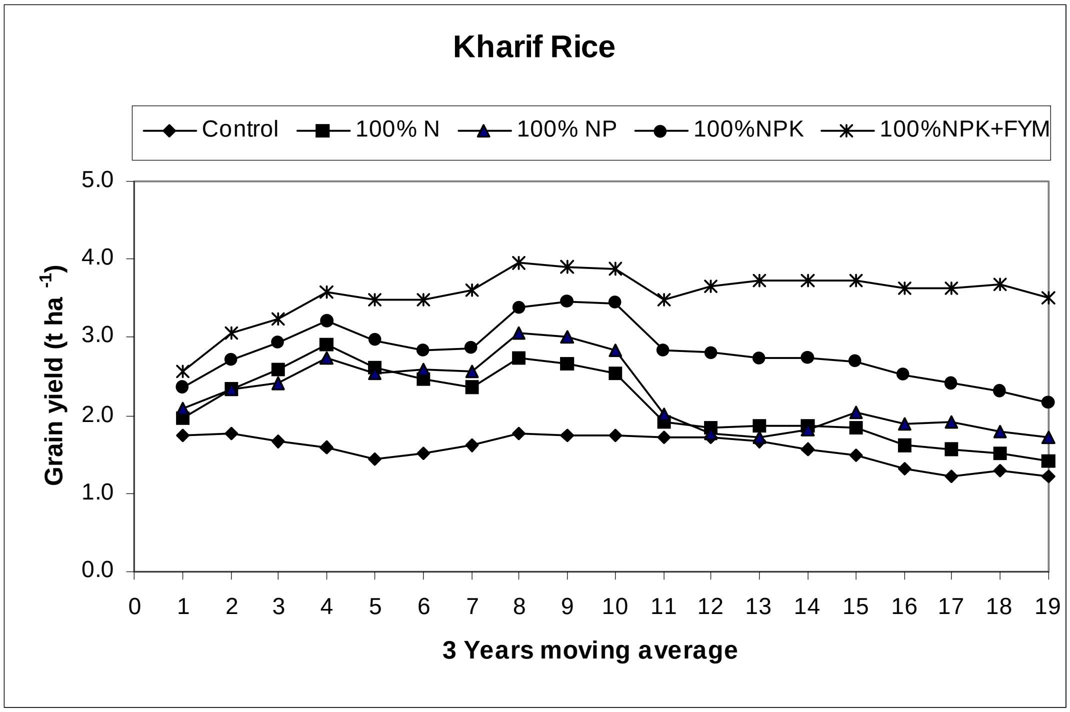


Fig. 3. *Grain yield (q ha-1) of fingermillet and hybrid maize (1986 to 2000) at Bangalore*



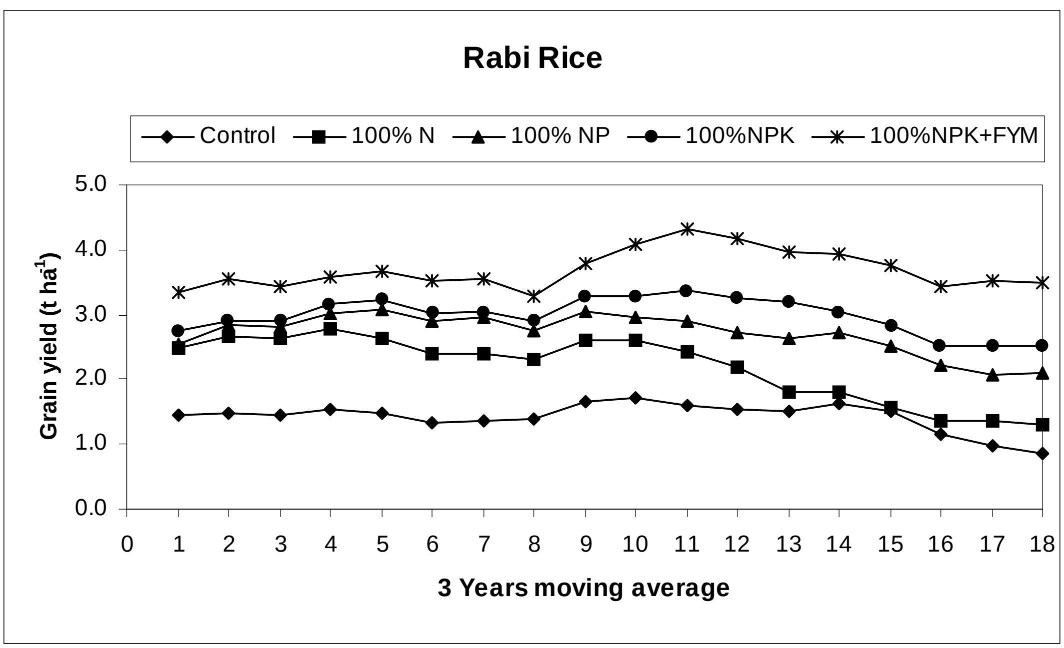


Fig. 4. *Effect of different fertilizer treatments on grain yield of Kharif and Rabi rice at Bhubaneswar*

Table 1: Average grain yield of crops (t/ha) and K response (kg/ha) over the years in long term experiments on yield stability and productivity

Centre	*Crops*	*NP (100% optimum)*	*NPK (100% optimum)*	*K response (kg/ha)*	*Response grain/kg K applied*
INCEPTISOLS					
Barrackpore	Rice	3.8	3.9	100	2.0
(1972-99)	wheat	2.3	2.4	100	2.2
Bhubaneswar	Rice	2.2	2.8	600	12.0
(1973-94)	Rice	2.8	3.0	200	4.0
Coimbatore	Fingermillet	2.9	3.0	100	7.1
(1972-99)	Maize	2.8	3.0	200	6.9
Delhi	Maize	1.8	2.1	300	9.0
(1994-99)	Wheat	4.3	4.6	300	9.0
Hyderabad	Rice	3.4	3.6	200	8.0
(1972-95)	Rice	2.2	2.6	400	16.0
Ludhiana	Maize	1.8	2.6	800	12.6
(1971-99)	Wheat	4.1	4.8	700	22.5
VERTISOL					
Jabalpur	Soybean	1.9	2.1	200	11.7
(1972-99)	Wheat	3.9	4.2	300	9.0
MOLLISOL					
Pantnagar	Rice	5.0	5.3	300	7.8
(1972-99)	Wheat	3.8	3.8	—	—
ALFISOLS					
Palampur	Maize	2.0	3.2	1200	36.3
(1973-99)	Wheat	1.8	2.5	700	18.4
Ranchi	Soybean	0.9	1.6	700	21.2
(1973-99)	Wheat	2.3	2.6	300	9.0
Bangalore	Fingermillet	1.2	4.3	3100	147.6
(1986-99)	Maize	0.8	2.2	1400	66.6

Table 2: Effect of super imposition of treatments on average grain yield of maize and wheat (t/ha) at Ludhiana (1994-99)

Original treatment	**Super imposed treatment**	**Maize**	**Wheat**
T_1 50% NPK	S_1 50% NPK	1.58	3.19
	S_2 100% N, 50% P, 50% K	2.28	4.74
	S_3 100% N, 50% P, 100% K + Zn	2.24	4.82
T_2 100% NPK	S_1 100% NPK	2.18	4.74
	S_2 100% N, 50% P, 100% K	2.20	4.85
	S_3 100% N, 50% P, 100% K + Zn	2.40	4.82
T_3 150% NPK	S_1 150% NPK	2.59	4.68
	S_2 150% N, 50% P, 150% K	2.35	4.69
	S_3 150% N, 50% P, 150% K + Zn	2.65	4.67

all soils thereby indicating continuous mining of soil K from non-exchangeable reserves (Swarup and Wanjari, 2000). The uptake data of various crops suggest that fertilizer K recommendations for crops should take into consideration non-exchangeable fraction of soil K.

The change in the cumulative release of K after 20 years of cropping from an Inceptisol at Hyderabad (**Fig. 5**) indicated the relative contribution of soil reserve K (non-exchangeable K) in crop K uptake. While there were fewer changes in the available K form during the period of 20 years, change in non-exchangeable K was more conspicuous. This shows the need to include non-exchangeable K in soil testing methodology, as it was more sensitive to crop K removal (Srinivasa Rao *et al.*, 2000). Similarly, there was considerable decrease in K release from non-exchangeable fraction of soil K with 20 years of cropping (**Fig. 6**).

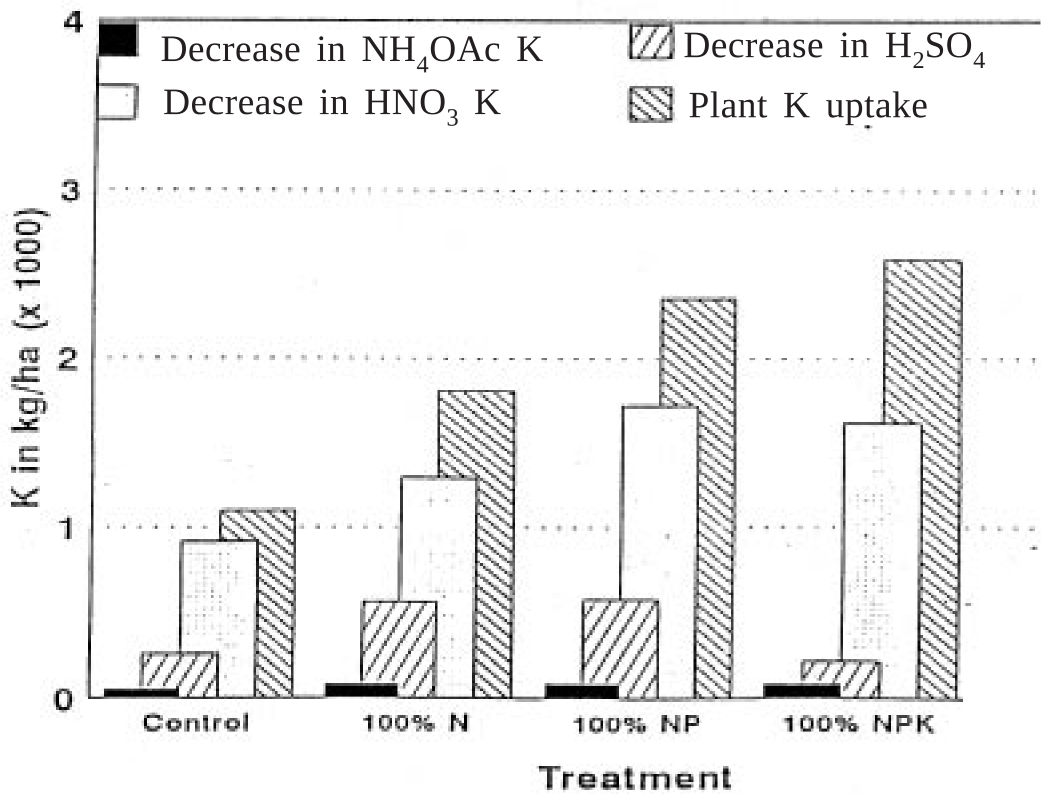


Fig. 5. Changes in different pools of K under different treatments with time at Hyderabad

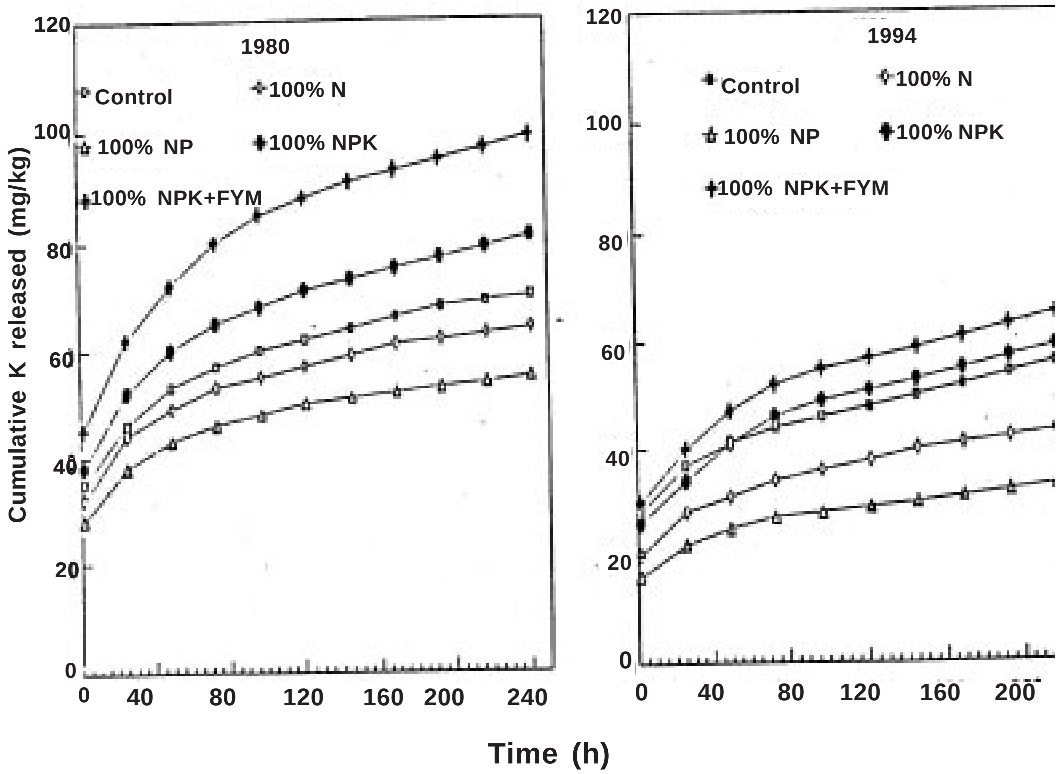


***Fig. 6:** Changes in cumulative K release from non-exchangeable K pool with time*

Build up and Depletion of Soil K

1. Continuous application of nitrogenous fertilizers alone to soils had a deleterious effect on soil productivity especially in soils deficient in P and K; the effects being more pronounced on Alfisols (Palampur, Ranchi and Bangalore). The available K status in these plots declined to less than critical levels (**Fig. 7**). 150% NPK or 100% NPK+FYM maintained higher available pools of K.

2. At Ludhiana and Palampur total productivity in the maize-wheat system increased over the years, mainly due to increased productivity of Wheat. This reflects that although the K level in the soil has improved over the years with the application of NPK but yet their optimum levels in the soil have not been attained. This behaviour is confirmed by available K status in the soil at both these centres. Similarly, in soybean-wheat system at Ranchi, the wheat yield has shown increasing trend over the years,

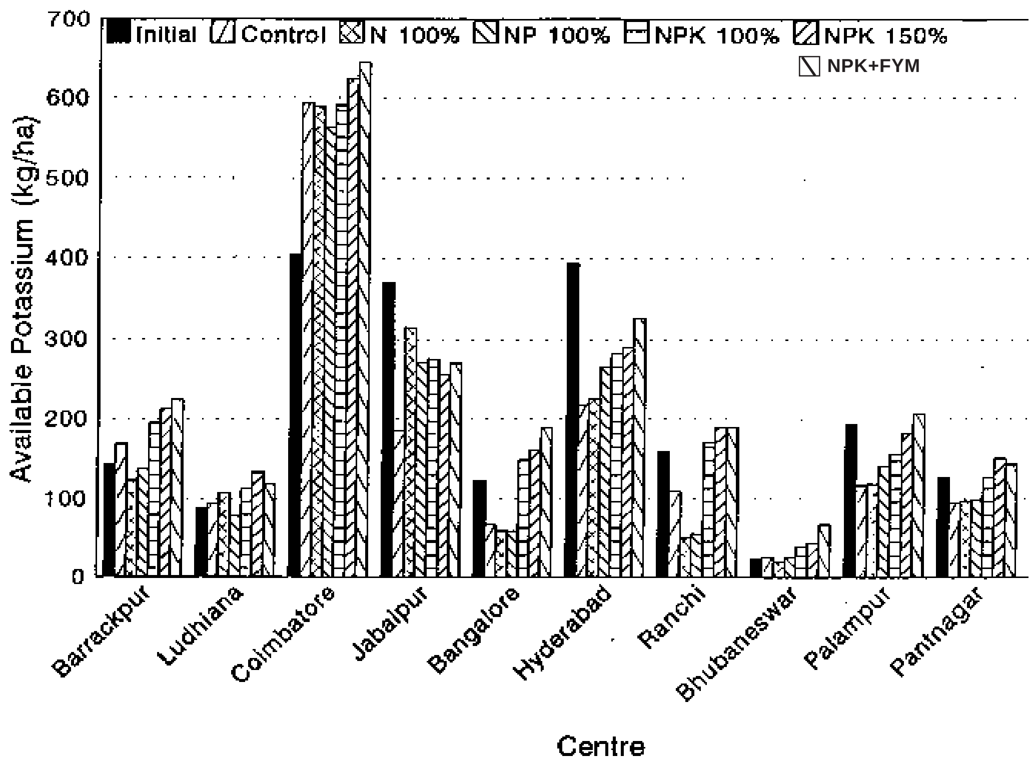


Fig. 7: Soil available K at different locations after long term cropping

obviously, due to improved status of K in the soil in NP treatment over N as the soil had deficiency of K to start with.

3. There is also evidence at many centres that the crops started drawing on the non-exchangeable source of K when the exchangeable K amount fell below the critical limits. An excellent example of such a change is provided by the experiment at Jabalpur and Bhubneswar centres. The results clearly showed that mining of soil K occurred even with NPK treatment. It is indicated that under intensive cropping, the K deficiency will gradually increase unless adequate quantity of K is added from external sources such as fertilizers and manures. Likewise, the results of experiments on finger millet-rabi maize cropping system at Bangalore clearly indicate that certain treatments with N alone or NP depressed the yields to the same level as the unmanured plot whereas with NPK or NPK + FYM treatments, the yields were stable at higher level. The available K status of the soil indicated that the soil was not able to meet the K demand of the crops. Thus severe K deficiency is limiting the responses to NP.

4. The declining trend in yield at many centres indicates the need for critical examination and modification of the existing K fertilizer recommendation to compensate for gradual loss of native soil K fertility. Results at Bhubaneswar centre (**Table 3**) with superimposed treatments showed that enhanced dose of K in excess of 100% NPK is extremely important for improving rice-rice productivity and maintaining available K in the soils.

Table 3: Effect of superimposition of treatments on grain yield of rice at Bhubaneswar

Superimposed treatment	*Grain yield (t ha^{-1})*					
	1994-95		*1995-96*		*1996-97*	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Treatment 8 of Replication III						
ST1-100% NPK + FYM	3.28	3.20	2.50	2.98	3.14	2.96
ST2-100% N + 50% P + 100% K + FYM	3.28	3.14	2.48	3.09	3.14	2.94
ST3-100% N + 50% P + 150% K + FYM	3.39	3.17	2.71	3.20	3.30	3.12

Non-exchangeable K release rates in different soil types under intensive cropping

Some workers have shown that intensive cropping for a long period would reduce the exchangeable K to a minimum level and at this level the release of non-exchangeable potassium starts (Sachdeva and Khera, 1980). Krishna Kumari *et al.* (1984) investigated the potassium release behaviour of an inceptisol (Holambi series) at the minimum level of exchangeable potassium and found that there was no response to potassium fertilizer applications, even when the soil was intensively fertilized with N and P without addition of potassium for ten years. Consecutively no K deficiency symptoms were exhibited by maize and wheat crops. On the basis of six successive cropping with pearlmillet, Mehta (1976) found that non-exchangeable K contributed 81% of the total K removed by plants in the alluvial soils of Gujarat. The reason proposed for the rapid release of non-exchangeable K under intensive cropping is that a concentration gradient is set up from high concentration of K in unexpanded towards the K depleted expanded part of the clay (Thomas, 1967).

Use of organic acids to extract non-exchangeable K from soil is believed to match the root extraction to soil K during intensive cropping. The cumulative K release was higher in Vertisols followed by Inceptisols and

Alfisols. Smectitic soil released about 25% whereas illitic soil released about 13% of non-exchangeable K to in malic acid.

Even though illite or mica is the primary source of non-exchangeable K in Inceptisols as well as Vertisols, the relative mobility of K from the illite minerals of Inceptisols is less compared to that of Vertisols. This is also observed from lower release rate constants of Inceptisols (3.5 h^{-1}), compared to Alfisols (3.52 h^{-1}) and Vertisols (4.03 h^{-1}). Differences in the composition of illite such as biotite or muscovite could make a very substantial difference in K release between Vertisols and Inceptisols (Srinivasa Rao *et al.*, 2001).

Changes in non-exchangeable K and its contribution to plant K uptake

Change in Non-exchangeable K of soils under intensive cropping has been observed in many cases irrespective of the available K status and dominant minerals of soils. Effect of long-term rice-rice cropping, fertilisation and manuring on K release pattern in 0.01 M $CaCl_2$ and by electro-ultra filtration (EUF) fraction (Srinivas Rao *et al.*, 2000) indicated a substantial reduction in K release from soils due to continuous cropping. Application of 100% NPK + 15 t FYM maintained higher K release whereas 100% NP showed the lowest K release. Non-exchangeable K released during 30-35 minutes in EUF extraction also indicated a similar change. It can be observed from the pattern of EUF desorption that K desorbed during the first 30 minutes (which indicates exchangeable from of K) did not vary much among treatments whereas the differences were much clear in EUF 30-35 K (Non-exchangeable K). Non-exchangeable release rate constants of Inceptisol as influenced by 14 years of rice-rice cropping, fertilization and manuring (**Table 4**) also indicated considerable decrease in non-exchangeable K release due to cropping

Table 4: Non-exchangeable K release rate constants in 0.01 M citric acid (zero order X 10^2) of Incptisols as influenced by 14 years rice-rice cropping, fertilization and manuring

Treatment	*1980*		*1994*	
	0-73 h	*0-217 h*	*0-73 h*	*0-217 h*
Control	53	29	33	22
100% N	40	26	33	20
100% NP	36	23	29	16
100% NPK	63	32	52	25
100% NPK+FYM	75	37	53	28

(Srinivasa Rao *et al.*, 1999). The differences were more clear during initial 73 hours of extraction as compared to release rates for the entire period of incubation.

Ten cycles of maize-wheat cropping at Ludhiana substantially reduced the non-exchangeable K especially under higher level of N and P application whereas application of 100 kg K ha^{-1} decreased the extent of change in non-exchangeable K (**Fig. 8**) at Ludhiana (Brar and Pasricha, 1998). Contribution of non-exchangeable K towards K uptake by crops as a result of K application decreased from 97% to 81% in a Vertisol at Jabalpur whereas it decreased from 100% to 27% in an Aeric Haplaquept at Bhubaneswar (**Table 5**). Reduction in non-exchangeable K under long-term cropping of finger millet-maize-cowpea sequence was observed in a Vertic Inceptisol at Coimbatore and under soybean-wheat-cowpea system at Jabalpur. In both the cases reductions were of larger magnitude in the absence of K supply (NP treatment) as compared to 100% NPK + FYM treatment. Similar observations were made by Subba Rao *et al.* (1993) in another long-term fertilizer experiment on alluvial soils with sorghum-wheat cropping at PRII, Gurgoan.

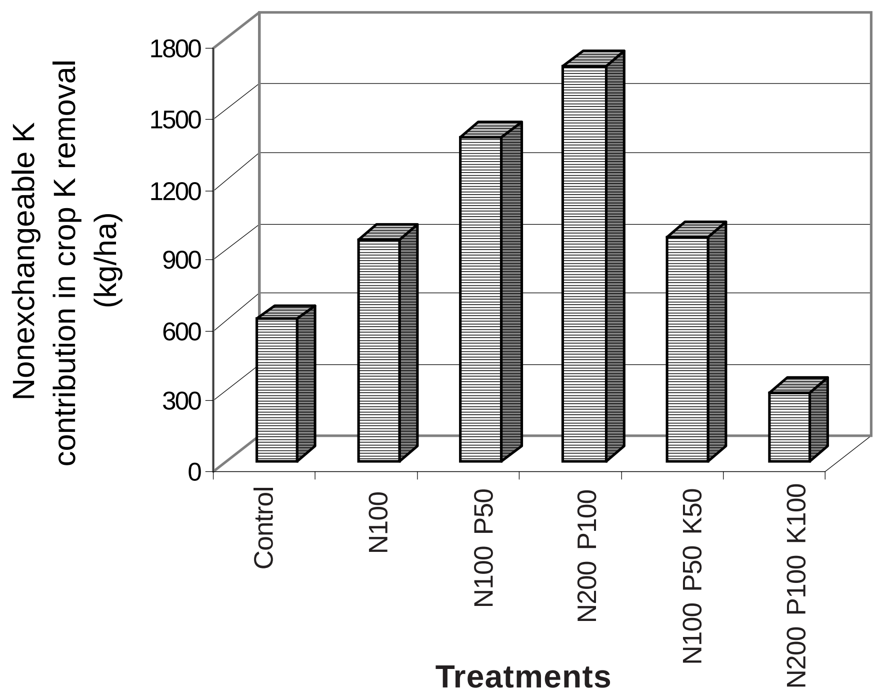


Fig. 8. *Contribution of nonexchangeable K to crop K removal during 10 cycles of maize-wheat cropping in a alluvial soil at Ludhiana*

Table 5: Removal and addition of potassium during 27 crop cycles of soybean-wheat-maize fodder * and 21 crop cycles of rice-rice rotations

Treatment	Fertilizer K added during 27 and 21 crop rotations		Available K (Kg ha^{-1})				Total K uptake (kg ha^{-1}) (kg ha^{-1})		Contribution of non-exch. K exch. K		% Contri-bution of non-	
			1		2							
	1	2	Cropping Before (1971)	Cropping After (1999)	Cropping Before (1971)	Cropping After (1994)	1	2	1	2	1	2
Control	0	0	370	252	25	32	3247	1176	3129	1183	96.4	100.5
100% N	0	0	370	263	25	20	4418	1743	4311	1738	97.6	99.7
100% NP	0	0	370	235	25	26	10067	1890	9932	1891	98.7	100.1
100% NPK	2117	2100	370	308	25	40	11826	2877	9647	792	81.6	27.5
100% NPK + FYM	4142	3150	370	324	25	67	14094	3507	9906	399	70.3	11.4

*Maize fodder crop was discontinued in the rotation since 1995; 1 = Typic Haplustert: (Jabalpur); 2 = Aeric Haplaquept (Bhubaneswar).

Quantity/Intensity relationships

Several researchers have used the quantity/intensity (Q/I) technique, which is the relationship between the amount (Q) present and the availability or intensity (I), to assess the status of soil potassium (K). Several studies have investigated the influence of K fertilization strategies on (Q/I) parameters in soil. These studies, however, did not evaluate the long-term effects of cropping, K fertilization and manuring on the Q/I relation in soils. Long-term experiments are an important means for obtaining information on the long-term sustainability of agricultural systems. A knowledge of Q/I relationship of potassium in soil together with their distribution in the zone of root penetration helps to predict the fate of added K in soil profile as well as nature of K supply from subsoil layers to plant K nutrition particularly in deep rooted crops and in formulating sound fertilizer recommendations.

Long-term cropping, fertilization, and manuring in a Typic Ustocrept at Delhi influenced the K supplying power of the top soil and subsoil layers, the effects being more pronounced on top soil. The highest and lowest values of equilibrium activity ratio (AR_e^k), labile pool of K (K_L), non-specific or immediately available K ($\triangle K_0$) and specific or difficulty available K (K_X) were observed in 100% NPK+FYM and 100% NP plots, respectively at all depths. Despite low AR_e^k, K_L and free energies of exchange for the replacement of calcium with potassium ($\triangle G$) values in control, N and NP plots, maize, wheat and cowpea did not show any deficiency symptoms thereby indicating that sufficient K is being released from non-exchangeable K source (Rupa *et al.*, 2001).

Conclusions

The long-term fertiliser experiments being carried out in different agroecological regions of India involving diversified intensive cropping systems and soil types have established increasing crop responses to K application, the effects being more pronounced in Alfisols and Inceptisols as compared to Vertisols and Mollisols. Continuous monitoring of available and non-exchangeable K status is extremely important for making sound K fertilizer recommendations for sustaining crop productivity in different soil types.

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