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Potassium Balances and Long-Term Sustainability of Sorghum-Wheat in an Alluvial Soil of Haryana, India

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Introduction

Potassium exists in four forms in soil: water soluble, exchangeable, non-exchangeable, and structural or mineral form. Equilibrium and kinetic reactions between these four forms of soil K determine the contribution of each soil K form in supplying growing crop plants via K from soil solution (Sparks and Huang, 1985). In alluvial soils in which mica is found as a dominant mineral, a substantial quantity of K is released from the mineral structure which provides most of the K taken up (Singh *et al.*, 2007). This release of K, however, is probably inadequate to sustain long-term crop cultivation and there is a need to investigate the contribution that it provides. A long-term field study was therefore carried out growing sorghum and wheat supplied with different levels of K fertilizer (and N and P) on an illite dominant Inceptisol soil of Southern Haryana. This experiment had three objectives: i) to quantify long-term K contribution of each soil K form to growing sorghum and wheat; ii) to quantify long-term K release from the structural form; and iii) to assess the effect of K release from structural soil K on long-term sustainability of growing sorghum and wheat.

Materials and Methods

A potassium balance sheet was drawn up using inputs including fertilizers, farmyard manure and irrigation water, and output through crop offtakes and soil K status in different treatments after 20 crop cycles in a long-term experiment which was started in 1985 on a loamy sand Udic Haplustept at the Potash Research Institute of India (PRII), Gurgaon, Haryana, India, involving a sorghum (fodder)-wheat cropping system. Both crops were irrigated occasionally to compensate for lack of precipitation.

Project location in India.

Soil

The major feature of this experiment was the K status of the soil on which the long-term field experiment was carried out, an illite dominated Inceptisol containing substantial amounts of K in mineral form. The initial chemical and physical characteristics of this soil, as well as the irrigation water used in 1985, are given in Table 1.

The soil with almost 80 percent sand, and about 10 percent silt and clay developed on alluvial parent material. Mica was present in all three fractions and was also the dominant mineral in the silt fraction in which K feldspars were present as an associate mineral. The clay fraction consisted of 40 percent illite, 15 percent vermiculite, 25 percent chlorite, 14.5 percent kaolinite, 5 percent amorphous material and 10 percent feldspar+quartz (Sekhon *et al.*, 1992). The pH of the soil was slightly alkaline and had a normal value of electrical conductivity. The soil for this long-term experiment was medium in both 1N NH_4OAc (water soluble and exchangeable K) and boiling 1N HNO_3 K (non-exchangeable K) in 1985, and had low organic carbon status (Table 1), but the soils of the area were considered to be a good supplier of K to growing crops. NH_4OAc-K, which includes water soluble and exchangeable

Table 1. Initial (1985) properties of the Udic Haplustept long-term experiment and average (140 irrigations) chemical composition of ground water used to irrigate sorghum and wheat in 20 crop cycles.

Parameter	Unit	Value
Soil (0-15 cm)		
pH (1:2)		8.2
EC (1:2)	dSm^{-1}	0.19
Organic Carbon	(mg kg^{-1})	2.37
CEC	(cmol(p^+)kg^{-1})	4.20
Sand	%	79.6
Silt	%	9.4
Clay	%	11.0
Texture		Loamy-sand
Classification		Udic Haplustept
Bulk Density	(Mg m^{-3})	1.48
Saturated Hydraulic-Conductivity	(cm h^{-1})	4.5
Alkaline $KMnO_4$ – N	(mg kg^{-1})	63.5
Olsen P	(mg kg^{-1})	2.4
1N NH_4OAc-K	(mg kg^{-1})	75.1
Non-exchangeable K	(mg kg^{-1})	773
Water		
pH		7.65
EC	(dSm^{-1})	1.15
Ca+Mg	(meq l^{-1})	5.50
Na^+	(meq l^{-1})	5.58
K^+	(mg l^{-1})	3.90
CO_3^{-2}	(meq l^{-1})	ND
HCO_3^-	(meq l^{-1})	6.4
SO_4^{-2}	(meq l^{-1})	ND
Cl^-	(meq l^{-1})	4.9
NO_3^-	(mg l^{-1})	22.5
SAR	(meq l^{-1})$^{0.5}$	3.37
RSC	(meq l^{-1})	0.9

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K, was determined according to Hanway and Heidel (1952).

Long-Term field experiment

In the field experiment there were seven treatment combinations with three levels of N (0, 120 and 240 kg ha^{-1} crop^{-1}), two levels of P (26.2 and 52.3 kg ha^{-1} crop^{-1}) and three levels of K (0, 49.8 and 99.6 kg ha^{-1} crop^{-1}). Each treatment was given to both wheat (in winter) and sorghum (in summer) (Table 2). These treatments were replicated three times in a randomized block design. Three levels of K (0, 49.8 and 98.8 kg ha^{-1} crop^{-1}) were applied along with the optimum recommended doses of 120 kg N and 26.2 kg P, two levels of K (0 and 99.6 kg K ha^{-1}) were applied at high doses of 240 kg N and 52.3 kg P. The doses of 120 kg N, 26.2 kg P and 49.8 kg K were integrated with 10 tonnes farmyard manure. The farmyard manure used in this experiment contained 0.5 percent K, equivalent to 50 kg K ha^{-1} year^{-1} in each wheat and sorghum.

During the period of 20 crop cycles, the sorghum was sown in the last week of June and harvested in the first week of September as a fodder crop, while wheat was sown in mid November and harvested in the second week of April. The full dose of P and K with half of the dose of N was applied at sowing time, and the remaining half dose of N was applied after the first irrigation in both crops. A uniform dose of 10 kg Zn ha^{-1} year^{-1} was also applied in the form of zinc sulfate heptahydrate. The sources of N, P and K were urea, di-ammonium phosphate (DAP) and potassium chloride (MOP), respectively.

During the 20 crop cycles, 140 irrigations - each having 7.5 cm depth - was applied using underground water. The average (of 140 irrigations) chemical composition of underground water used in irrigation is given in Table 1. Total K contribution from underground water was computed by multiplying the amount of water applied by the average K concentration of water applied in 20 crop cycles.

Table 2. Treatments of the long-term fertilizer experiment, 1985-2005.

Treatment	Nutrient level
	kg ha^{-1}
Control	0
$N_1P_1K_0$	120-26.2-0
$N_2P_2K_0$	240-52.3-0
$N_1P_1K_1$	120-26.2-49.8
$N_1P_1K_2$	120-26.2-99.6
$N_2P_2K_2$	240-52.3-99.6
$N_1P_1K_1$+FYM	120-26.2-49.8+10 mt FYM

Note: P and K are represented in their elemental forms.

Harvested plant samples were weighed then oven-dried at 70°C to constant weight and ground to a fine powder. Measurement of K was carried out by the standard method of flame photometry following acid digestion ($HCl-HNO_3$).

Total K offtake by wheat and sorghum in 20 crop cycles was calculated by multiplying the K content in fodder for sorghum and grain and straw for wheat by their respective yields. K contribution from different forms of soil K was assessed by taking into account the changes in 1N NH_4OAc-K, and non-exchangeable K in 20 crop cycles. K released from the structural form of soil K was calculated using the following formula:

tKr = t K off – depinsoil + bupinsoil – K added

tKr = total K released in 20 crop cycles from the structural form of soil K (kg K ha^{-1}); tK off = total K removed by wheat and sorghum in 20 cycles (kg K ha^{-1}); depinsoil = net depletion in NH_4OAc and non-exchangeable K status of soil in 20 cycles (kg K ha^{-1}); bupinsoil = net build up in NH_4OAc and non-exchangeable K status of soil in 20 cycles (kg K ha^{-1}); K added = total amount of K added in 20 cycles through fertilizer, manure and from irrigation water (kg K ha^{-1}). Leaching and deposition of K were neither measured nor calculated in this experiment.

Results and Discussion

Wheat yields

Cumulative wheat grain yield over the 20 years presents a different picture from sorghum (Fig. 1). Cumulative wheat grain yield in the control was only 18.1 mt ha^{-1} which increased five fold to 94.9 mt ha^{-1} by NP application with $N_{120}P_{26.2}K_0$. Application of 49.8 kg ha^{-1} crop^{-1} year^{-1} in $N_1P_1K_1$ produced a cumulative wheat grain yield of 103.1 mt ha^{-1} which works out to be a response of about 9 percent for the K applied. Applying a higher dose of K (99.6 kg K ha^{-1} year^{-1}) with $N_{120}P_{26.2}$ did

Table 3. Offtake of K by wheat and sorghum in 20 crop cycles.

Treatments kg ha^{-1} crop^{-1}	Wheat Grain	Wheat Straw	Wheat Total	Sorghum	Total
	---kg ha^{-1}---				
$N_0P_0K_0$	107	536	643	947	1590
$N_{120}P_{26.2}K_0$	484	1,497	1,981	1,131	3,112
$N_{240}P_{52.3}K_0$	497	1,154	1,651	632	2,283
$N_{120}P_{26.2}K_{49.8}$	557	2,352	2,909	1,546	4,455
$N_{120}P_{26.2}K_{99.6}$	561	2,835	3,396	2,592	5,988
$N_{240}P_{52.3}K_{99.6}$	585	3,099	3,684	2,047	5,731
$N_{120}P_{26.2}K_{49.8}$ +10 mt FYM	568	2,818	3,386	2,177	5,563
C.D ($P \leq 0.05$)	55	154		145	

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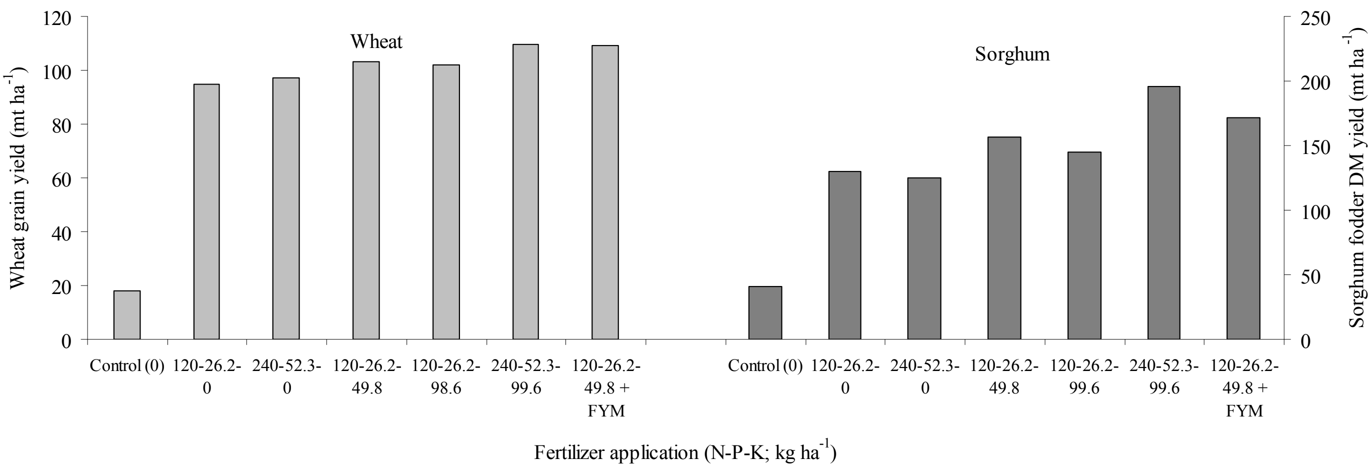

Fig. 1. Cumulative grain yields of wheat and DM of sorghum over 20 years (1985-2005).

not show any benefit as the cumulative grain yield was only 102 mt ha^{-1}. However, applying 10 mt FYM with the $N_{120}P_{26.2}K_{49.6}$ treatment produced a cumulative grain yield of 109.2 mt ha^{-1} which was on a par with that of the $N_{240}P_{52.3}K_{99.6}$ treatment (109.8 mt ha^{-1}), showing the greater advantage of FYM application for the grain crop of wheat as compared to that of the fodder crop of sorghum. Application of the $N_{240}P_{52.3}K_{99.6}$ treatment produced 109.8 mt ha^{-1} of cumulative wheat grain yield which was about 12.8 percent more than for the $N_{240}P_{52.3}K_0$ treatment (97.3 mt ha^{-1}).

Sorghum yields

Cumulative crop yields of sorghum (fodder) dry matter (DM) and wheat grain over the 20 crop cycles are shown in Fig. 1. Cumulative sorghum DM yield in the control ($N_0P_0K_0$) was 40.7 mt ha^{-1}, which rose to 130.1 mt ha^{-1} in the $N_{120}P_{26.2}K_0$ treatment and increased further by about 12 percent to 156.7 mt ha^{-1} by the additional application of 49.8 kg K ha^{-1} crop^{-1} year^{-1} (treatment $N_{120}P_{26.2}K_{49.8}$). Doubling the application of N and P, but without K, ($N_{240}P_{52.3}K_0$) reduced the sorghum DM yield to 125.4 mt ha^{-1}. The highest cumulative yield of 196 mt ha^{-1} was obtained by doubling the application of K to 98.6 kg K ha^{-1} crop^{-1} year^{-1} together with the doubled N and P ($N_{240}P_{52.3}K_{99.6}$). This led to an increase of about 56.8 percent in DM yield over that without K, ($N_{240}P_{52.3}K_0$). The treatment with 10 mt FYM associated with low levels of N, P, and K application in the form of mineral fertilizers did not compensate for the lower amount of mineral fertilizer nutrients applied and DM yields were correspondingly lower than in the $N_{240}P_{52.3}K_{99.6}$ treatment.

Application of FYM differs in its effect on wheat grain yield and dry matter yield of vegetative sorghum. For wheat application of FYM, together with relatively low levels of NPK ($N_{120}P_{26.2}K_{49.8}$), may be sufficient for sustainable production, whereas for high sorghum fodder yields, it is essential to apply twice as much mineral fertilizer as N, P and K, ($N_{240}P_{52.3}K_{99.6}$), with the benefit of additional FYM seen only at the lower mineral fertilizer application rate ($N_{120}P_{26.2}$ $K_{49.8}$).

Potassium offtake for wheat

Potassium offtake in the various treatments varied greatly and for the whole cropping system (including sorghum and wheat) increased almost four-fold as compared to the control (Table 3). For wheat, potassium offtake tripled after fertilizing with N and P ($N_{120}P_{26.2}K_0$) as compared to the control, demonstrating the effect of increased K offtake just by applying N and P. The magnitude of increase in offtake by grain and straw was similar: K offtake by grain increased from 107 to 484, and that of straw from 536 to 1497 kg K ha^{-1}. Adding K fertilizer ($N_{120}P_{26.2}K_{49.8}$) significantly increased K offtake, mostly in the straw. Highest K offtake in wheat was in the treatment that achieved the highest yield with high K ($N_{240}P_{52.3}K_{98.6}$) at 3,684 kg K offtake over 20 years.

Potassium offtake for sorghum

Similar to wheat, application of N and P (compared with the control) increased yields and hence also K offtake but at a much lower magnitude (2.5 fold). Highest K offtake by sorghum was at $N_{120}P_{26.2}K_{99.6}$. However, this treatment was not the best in terms of DM production.

Potassium status in soil

Increase in the exchangeable potassium was evident only with the high K applications ($K_{99.6}$) in both horizons or with FYM for the A horizon (A – 0-15 cm and B – 15-30 cm; Table 4). In general, exchangeable K in the upper

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Table 4. Changes in 1N NH_4OAc-K (water soluble plus exchangeable K) and non-exchangeable K status of the Udic Haplustept over 20 crop cycles.

Treatments N-P-K	1N NH_4OAc K status and change							Non-exchangeable K status and change						
	1985		2005		Delta 2005-1985			1985		2005		Delta 2005-1985		
	A	B	A	B	A	B	Total	A	B	A	B	A	B	Total
kg ha⁻¹ crop⁻¹	---*kg ha⁻¹*---													
$N_0P_0K_0$	169	126	147	112	-22	-14	-36	1,909	1,503	1,772	1,559	-137	+56	-81
$N_{120}P_{26.2}K_0$			103	99	-66	-27	-93			1,570	1,636	-339	+133	-206
$N_{240}P_{52.3}K_0$			104	97	-65	-29	-94			1,512	1,577	-397	+74	-323
$N_{120}P_{26.2}K_{49.8}$			141	109	-28	-17	-45			1,785	1,652	-124	+149	+25
$N_{120}P_{26.2}K_{99.6}$			206	140	+37	+14	+51			1,897	1,817	-12	+314	+302
$N_{240}P_{52.3}K_{99.6}$			198	109	+29	-17	+12			1,747	1,622	-162	+119	-43
$N_{120}P_{26.2}K_{49.8}$ +10 mt FYM			172	107	+3	-19	-16			1,759	1,696	-150	+193	+43
C.D ($P \leq 0.05$)	NS	NS	36	9				NS	NS	77	121			

Note: A=0-15 cm; B=15-30 cm.

horizons (0-15 cm) were depressed more than the 15-30 cm, whilst changes in exchangeable K were from -94 to +51 kg ha^{-1} during the period 1985-2005.

Non-exchangeable K showed depletion of K in the A horizon (0-15 cm) but build up of K in the B horizon, yet, the total calculation for the 0-30 cm showed decline in non-exchangeable K in most of the treatments (Table 4). Non-exchangeable form of soil K is held between adjacent tetrahedral layers of dioctahedral and trioctahedral mica, and is only moderately to sparingly available to crop plants (Sparks and Huang 1987). In 20 cycles, this form of soil K contributed 6.62 percent K to the total K removed by sorghum and wheat, which were grown with the recommended doses of N and P ($N_{120}P_{26.2}K_0$) (Table 3 and Fig. 2). This K contribution was attributed to net 206 kg K ha^{-1} decrease in value of this form, both at surface and subsurface layers of plots receiving the treatment $N_{120}P_{26.2}K_0$ (Table 4).

Negative changes in exchangeable and non exchangeable K in soil occurred in conjunction with low yields and K offtake (Fig. 1 and 2) which were with the zero K treatments. Application of K in any of the treatments dramatically changes the soil K balance (Fig. 2).

The above findings show that K released from the structural form was unable to sustain sorghum and wheat productivity at optimum levels. Consequently, both sorghum and wheat responded significantly to applied K fertilizer; sorghum responding to a greater extent in comparison to wheat (Fig. 1). Sorghum, owing to its shallow root system, only absorbs K from the surface layers of the soil, whereas

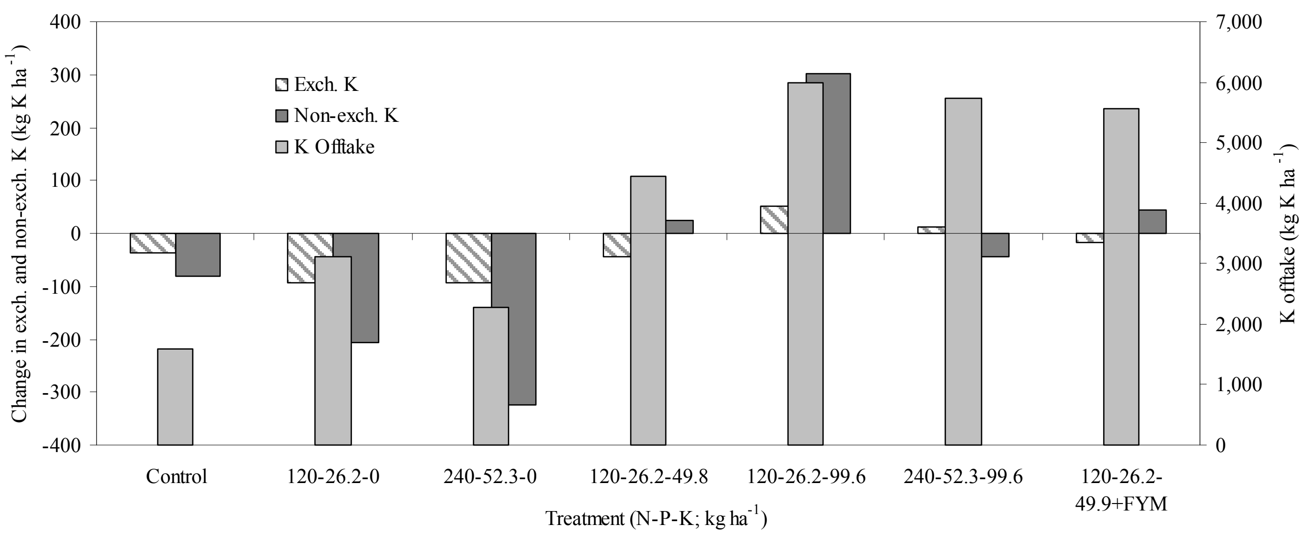

Fig. 2. Change in exchangeable and non-exchangeable K and K offtake during 1985-2005.

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wheat, on the other hand, absorbs K from the surface and subsurface layers due to its deep root system. For this reason, greater responses to applied K fertilizer were found in sorghum rather than wheat.

Exchangeable K forms of soil, contributed 3 percent K, and non-exchangeable K form contributed 6.6 percent K to the total K removed by sorghum and wheat over 20 crop cycles. Ground water used in irrigations contributed 13.1 percent K. The contribution of soil K forms to growing sorghum and wheat including the K release from the structural form, decreased significantly with the K fertilizer application to the growing crops.

Table 5. Balance of K between the various sources (1985-2005).

Treatments	Output of K(1): Total K offtake by the crops	Inputs of K by sources(1) (depinsoil + bupinsoil): Irrigation water	Fertilizer	Soil water soluble& exchangeable K	Soil non-exchangeable K	Net depletion of soil K from structural K(2) (tKr)
kg ha⁻¹ crop⁻¹	kg ha⁻¹					
$N_0P_0K_0$	1590	409	0	36	81	1064
$N_{120}P_{26.2}K_0$	3112	409	0	93	206	2404
$N_{240}P_{52.3}K_0$	2283	409	0	94	323	1457
$N_{120}P_{26.2}K_{49.8}$	4455	409	1992	45	0	2034
$N_{120}P_{26.2}K_{98.6}$	5988	409	3984	0	0	1948
$N_{240}P_{52.3}K_{98.6}$	5731	409	3984	0	43	1307
$N_{120}P_{26.2}K_{49.8}$ +10 mt FYM	5563	409	3992	16	0	1189

(1)Analyzed; (2)Calculated

Potassium balance

Our results show that the structural K form or lattice K form, which is found in K feldspars, mica and in other K bearing minerals, released a substantial amount of K which contributed most of the K required during 20 growing cycles of sorghum and wheat. Overall, however, this release still fell short in meeting the entire crop K needs. In plots receiving the treatment $N_{120}P_{26.2}K_0$, as much as 2,404 kg K ha^{-1} was released from the structural form of soil K which contributed 77.25 percent K to the total K removed by growing sorghum and wheat over 20 cycles (Table 5 and Fig. 3). Similarly in plots in which sorghum and wheat was grown with the treatment $N_{240}P_{52.3}K_0$, 1,457 kg K ha^{-1} was released from this form which contributed 63.8 percent K.

The rate of K release from the structural form decreased significantly with K fertilizer application, consequently, K contribution of this form decreased (Table 5). The most important factor that controls the rate of K release from

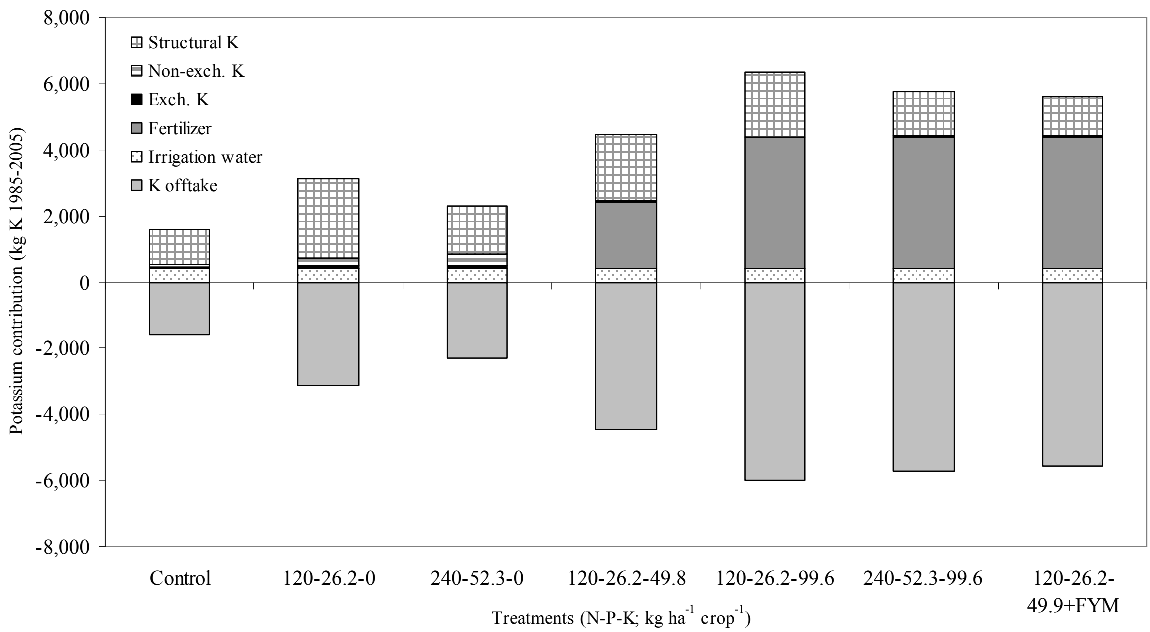

Fig. 3. Total inputs and outputs of K in wheat-sorghum cropping system during 1985-2005.

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the structural form is the concentration of K in soil solution. The higher the K concentration in soil solution, the lower the K release from the structural form. Hence, the greater K in soil solution for the K fertilized plots (Table 5) in this long-term experiment must have decreased the release of structural K.

Conclusion

It is concluded that despite substantial K release from the structural form in an Udic Haplustept which contributed 77.3 percent K of the total K removed by sorghum and wheat in a long-term experiment (20 crop cycles), K fertilizer is still needed to maintain K fertility and sustain yields in the cultivation of these crops on this loamy sand soil rich in illite.

These findings refute the general myth that illite dominant alluvial soils of north-western India contain soil reserves of K sufficient to sustain K supply to growing crops over long-periods without any K fertilization. Another, belief that the amount of K in irrigation water in the area is enough to sustain the K requirements of growing crops has also been shown to be wrong. This long-term study conclusively proved that sufficient K fertilization (at 49.8 kg K ha^{-1} $crop^{-1}$) to each crop is needed to sustain optimum crop productivity despite the high contributions from the structural K form. This study also proved that application of high doses of N and P without K (which is a general practice in the area) could be detrimental to both soil and crop productivity on a long-term basis.

Exchangeable and soluble forms of soil K contributed least K to growing sorghum and wheat. The K contribution of non-exchangeable form was found to be much less than that of the structural form of soil K.

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The paper "Potassium Balances and Long-Term Sustainability of Sorghum-Wheat in an Alluvial Soil of Haryana, India" is also available at:

Regional Activities/India

The Rothamsted Long-Term Experiments: Are They Still of Use?

Jenkinson, D.S. AFRC Inst. of Arable Crops Res. Rothamsted Exp. Stn., Harpenden, Herts AL5 2JQ, England. Agron J 83:2-10. 1991.

The Rothamsted long-term experiments-the Classicals-were started almost 150 yr ago. These experiments were originally designed to study the N, P, K, Na, Mg, and Si needs of the field crops then grown in England. This was done by comparing these inorganic nutrients, in various combinations, with farmyard manure, the traditional source of fertility at that time. Although the questions the experiments were originally designed to answer have long been re-solved, the experiments continue to give results of interest to agron omists, ecologists, soil scientists, plant pathologists, and others. The experiments show that grain yields can be sustained (and even increased) for almost 150 years in monocultures of wheat and barley given organic or inorganic fertilizer annually. They provide data on the long-term effects of inorganic fertilizers and organic manures on soil organic matter levels. These data have been used to test computer-based models for the turnover of organic matter in soil. Again, long-term N balances show that there are considerable inputs of N to the soil/plant system, amounting to some 30 kg N ha^{-1} yr^{-1} in unfertilized wheat and up to 65 kg ha^{-1} yr^{-1} in an arable soil reverting to woodland. These and other results are used to consider the advantages and disadvantages of long-term experiments. Wisely used, long-term experimental sites provide information on the long-term sustainability of agricultural systems that can be obtained in no other way.