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Build up and depletion of soil phosphorus and potassium and their uptake by rice and wheat in a long-term field experiment

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Summary In a field experiment initiated at the Central Soil Salinity Research Institute, Karnal in 1974 involving rice wheat cropping sequence and NPK fertilizer use on sodic soil (pH 9.2, ESP 32.0), an attempt was made to evaluate the available P and K status of the soil and their uptake by the crops during 1982–83 and 83–84.

Application of P to either or both the crops significantly enhanced the yields of rice and improved available P status of the soil. Wheat yields remained unaffected. Fertilizer N reduced P content in rice but increased P uptake in crops and considerably brought down available P to a level (4.5 ppm) where rice plants showed reduced tillering and phosphorus deficiency. Application of K did not affect the yield of either crop but enhanced its available status in soil and uptake by the crops. Contribution of the non-exchangeable K towards total potassium removal was about 93% in the absence of applied K which decreased to 87% with the use of K. Application of K to both crops resulted in lesser uptake from non-exchangeable form as compared to its application to either crop. Laboratory studies carried out on soils of the experimental plots showed that cumulative K release measured after five successive extractions was higher in K-treated soils as compared to untreated ones. The major difference was only in the first extraction representing the exchangeable K after which release became independent of the available K of the soil.

Introduction

With the advent of high-yielding fertilizer-responsive varieties of cereals there is vast scope of increasing food production by utilizing hitherto barren and unproductive sodic soils of the Indo-Gangetic alluvial plains of Northern India which occupy nearly 2.5 million hectares. After application of gypsum or other suitable soil amendments to these soils, a rice-wheat cropping sequence can be practiced and has, in fact come to be a stable system in this area. Normally, major nutrients like N, P and K are recommended on the basis of soil tests. However, there is need to assess whether these nutrients especially P and K are actually required continuously for both crops or not. Moreover, build up and depletion of P and K in a cropping sequence is one of the most important factors which determine whether a crop will respond or not to the applied nutrients. It is also well known that continuous cropping results in the depletion of soil P and K; with fertilizer use the status of these nutrients in soil is either maintained at the original level or even increased[2,3,6,11] Information on these aspects in alkali soils is rather limited and therefore an attempt was made to study the behaviour of P and K in soil and their uptake by rice and wheat in a long term experiment.

Materials and methods

A long-term field experiment was started in 1974 on a partially reclaimed sodic soil in a fixed layout having rice-wheat sequence. The soil was highly sodic, but after adding gypsum and growing crops since 1971, its pH and ESP got reduced to 9.2 and 32.0 respectively, in the surface layer (0–15 cm). Some of the initial soil properties are presented in Table 1. There were 8 treatment combinations (Table 2) replicated 4 times in a randomized block design. Plot size was 24 m^2. N, P and K were applied @ 100, 22 and 42 kg/ha respectively, according to treatments (Table 2). Dose of N was raised from 100 to 120 kg/ha beginning with the rice crop of 1978. Half the dose of N and the full dose of P and K were given before transplanting of rice and sowing of wheat during 1974–75 and 1983–84. The remaining half of the N was top dressed in 2 equal splits when the crops were 3 and 6 weeks old. The sources of N, P and K were urea, single superphosphate and muriate of potash respectively. All the recommended agronomic practices were followed. Rice variety Jaya and wheat HD-2009 were grown as the test crops. Grain yield of rice was computed on 14 percent moisture content and straw yield on oven dry basis whereas in wheat, yields of both grain and straw were recorded on air-dry basis. To compute uptake of P and K, straw and grain samples were collected at the harvesting time of rice and wheat from each plot. The samples were washed well in distilled water, dried in air and oven at 60°C to constant weight. Straw samples were ground to pass through a one-mm sieve whereas the intact grains of unhusked rice and wheat were taken as such for chemical analysis[4]. P was determined by vanadomolybdophosphoric yellow colour method and the flame photometer was used for determing the K. Soil samples (0–15 and 15–30 cm soil depth) were collected after the harvest of rice and wheat, ground to pass through a 2 mm sieve and analysed.

Results and discussion

Effect of P on yield, P content and uptake

Application of P to either or both the crops significantly enhanced the grain yield of rice (Table 2) as the available P in the soil had come down to less than critical level (Table 7) of 5 ppm[7] after 1983 rice. The available P in soil after 1982 rice was more than 5 ppm (Table 7) in plots receiving only N (Treatment 2) and hence the level of magnitude of response to applied P (treatment 3) was less in 1982 (0.55 t/ha) as compared to 1983 rice (1.94 t/ha). Pooled analysis of the ten year data also showed significant effect of P on the rice yields (Table 2). In this experiment rice responded to P application only after 1978 and there was no effect on yields in the earlier years of the experiment when the soil had high amounts of this nutrient[1]. Wheat yields remained unaffected. Phosphate fertilization significantly enhanced the P content of the test crops irrespective of its effect on yield and contributed

Table 1. Soil analysis of experimental field

Mechanical analysis[a]	
Sand (%)	51.6
Silt (%)	24.3
Clay (%)	24.1
Soil pH[b]	9.2
Exchangeable sodium percentage[c]	32
Cation exchange capacity meq/100 g[c]	8.8
$CaCO_3$ (%)[c]	2.75
Organic carbon (%)[c]	0.25
Available P (ppm)[d]	15
Available K (ppm)[e]	160

[a] International pipette method.
[b] 1:2 soil water suspension.
[c] Jackson[4].
[d] Olsen *et al.*[7]
[e] 1:5 Soil – 1 *N* NH_4OAC pH 7.0 extract.

towards higher uptake (Table 3, 4). This sort of a direct influence of soluble phosphatic fertilizers has been seen in many field studies[8,11]. The P content of the rice plants (1983) at 30 days in N alone treatment was also reduced to deficient level (Table 3). However, P uptake was higher than control because of high dry matter production (Table 2). The reverse was the trend with wheat where N enhanced the P content and uptake and no response to applied P was observed so far. The soil under investigation had high amount of available P in lower (15–30 cm) depths (Table 7) which has not yet come down to critical level. It is well known that wheat roots go deeper in soil as compared to rice[5] and thus might be satisfying their P requirement. Moreover, the uptake of P by wheat is less than rice which is indicated by low yields and decreased uptake (Table 2, 4). These could be the possible reasons for the lack of response of P in wheat. The P content and uptake remained unaffected due to K application.

The only two treatments where there was a continuous decline in available P from the initial level happened to be control and N alone (Table 7). P application to both crops in rotation (treatments 3 and 6) resulted in 85.3 to 90.6% increase in available P in 0–15 cm soil depth over the initial status after 20 crops (1983–84 wheat). All other treatments involving the use of P either to rice or wheat did not differ significantly and reflected in marginal improvement which varied from 38.6% to 44.6%. When N alone was applied the available P decreased markedly by 70% (from 15.0 to 4.5 ppm) over the initial status because of enhanced dry matter production and consequent higher uptake of P by crops (Table 2, 4). At these levels of P in the soil (4.8 to 4.5 ppm) rice plants showed reduced tillering and P

Table 2. Grain yields (t/ha) of rice and wheat on sodic soil

Treatment		Rice			Wheat		
Rice	Wheat	1982	1983	Average of 10 years (1974 to 1983)	1982–83	1983–84	Average of 10 years (1974–75 to 83–84)
$N_0P_0K_0$	$N_0P_0K_0$	3.50	3.10	3.41	1.15	0.97	1.18
N_{120}	N_{120}	6.00	3.87	6.55	4.61	4.54	4.30
$N_{120}P_{22}$	$N_{120}P_{22}$	6.55	5.81	7.24	4.50	4.80	4.24
$N_{120}P_{22}$	N_{120}	6.01	5.22	7.06	4.85	4.88	4.37
N_{120}	$N_{120}P_{22}$	6.35	5.43	7.15	4.68	4.83	4.34
$N_{120}P_{22}K_{42}$	$N_{120}P_{22}K_{42}$	6.35	5.51	7.03	4.60	4.86	4.34
$N_{120}P_{22}K_{42}$	N_{120}	6.50	5.26	7.14	4.66	4.57	4.25
N_{120}	$N_{120}P_{22}K_{42}$	6.28	5.13	6.83	4.66	4.64	4.26
C.D. (0.05)		0.50	0.46	0.45	0.71	0.39	0.35

Table 3. Phosphorus content (%) of rice and wheat

Treatment		Rice					Wheat			
		1982		1983			1982–83		1983–84	
Rice	Wheat	Grain	Straw	30 days plants	Grain	Straw	Grain	Straw	Grain	Straw
$N_0P_0K_0$	$N_0P_0K_0$	0.300	0.035	0.158	0.295	0.032	0.286	0.034	0.294	0.031
N_{120}	N_{120}	0.288	0.030	0.125	0.284	0.028	0.345	0.036	0.352	0.034
$N_{120}P_{22}$	$N_{120}P_{22}$	0.386	0.042	0.228	0.395	0.044	0.388	0.041	0.395	0.040
$N_{120}P_{22}$	N_{120}	0.375	0.040	0.225	0.398	0.043	0.390	0.038	0.388	0.039
N_{120}	$N_{120}P_{22}$	0.388	0.041	0.219	0.400	0.042	0.378	0.039	0.392	0.039
$N_{120}P_{22}K_{42}$	$N_{120}P_{22}K_{42}$	0.400	0.043	0.230	0.399	0.044	0.395	0.042	0.400	0.041
$N_{120}P_{22}K_{42}$	N_{120}	0.392	0.039	0.220	0.402	0.042	0.386	0.040	0.389	0.038
N_{120}	$N_{120}P_{22}K_{42}$	0.388	0.040	0.218	0.415	0.042	0.392	0.039	0.390	0.039
C.D. (0.05)		0.068	0.007	0.065	0.056	0.006	0.038	0.005	0.036	0.005

Table 4. Phosphorus uptake (kg/ha) by rice and wheat

Treatment		Rice						Wheat					
		1982			1983			1982–83			1983–84		
Rice	Wheat	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
$N_0P_0K_0$	$N_0P_0K_0$	10.5	1.5	12.0	9.1	1.3	10.4	3.2	0.5	3.7	2.8	0.4	3.2
N_{120}	N_{120}	17.2	2.4	19.6	10.9	1.5	12.4	15.9	1.8	17.7	15.9	1.5	17.4
$N_{120}P_{22}$	$N_{120}P_{22}$	25.2	3.5	28.7	22.9	3.3	26.2	17.4	2.2	19.6	18.9	2.6	21.5
$N_{120}P_{22}$	N_{120}	22.5	3.2	25.7	20.7	3.1	23.8	18.9	2.1	21.0	18.9	2.4	21.3
N_{120}	$N_{120}P_{22}$	24.6	3.4	28.0	21.7	3.1	24.8	17.6	2.0	19.6	18.9	2.4	21.3
$N_{120}P_{22}K_{42}$	$N_{120}P_{22}K_{42}$	25.4	3.5	28.9	21.9	3.3	25.2	18.1	2.3	20.4	19.4	2.5	21.9
$N_{120}P_{22}K_{42}$	N_{120}	25.4	3.1	28.5	21.1	3.0	24.1	17.9	2.2	20.1	17.7	2.3	20.0
N_{120}	$N_{120}P_{22}K_{42}$	24.3	3.3	27.6	21.2	3.0	24.2	18.2	2.1	20.3	18.0	2.3	20.3

Table 5. Potassium content (%) of rice and wheat

Treatment		Rice				Wheat			
		1982		1983		1982–83		1983–84	
Rice	Wheat	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
$N_0P_0K_0$	$N_0P_0K_0$	0.37	1.52	0.38	1.65	0.34	1.17	0.36	1.27
N_{120}	N_{120}	0.36	1.75	0.37	1.83	0.35	1.21	0.38	1.35
$N_{120}P_{22}$	$N_{120}P_{22}$	0.38	1.82	0.38	1.88	0.36	1.33	0.37	1.38
$N_{120}P_{22}$	N_{120}	0.37	1.78	0.37	1.85	0.35	1.34	0.38	1.37
N_{120}	$N_{120}P_{22}$	0.37	1.80	0.37	1.82	0.35	1.35	0.39	1.39
$N_{120}P_{22}K_{42}$	$N_{120}P_{22}K_{42}$	0.38	1.98	0.39	2.15	0.36	1.48	0.40	1.52
$N_{120}P_{22}K_{42}$	N_{120}	0.39	1.95	0.39	1.98	0.37	1.41	0.37	1.41
N_{120}	$N_{120}P_{22}K_{42}$	0.38	1.95	0.40	1.96	0.36	1.42	0.38	1.43
C.D. (0.05)		NS	0.11	NS	0.12	NS	0.13	NS	0.12

Table 6. Removal and addition of potassium (kg/ha) in two years of cropping sequence (1982–83 and 83–84)

Treatment		Available K (kg/ha)			K uptake (kg/ha)				
Rice	Wheat	Before 1982 rice	After 1983–84 wheat	Fertilizer K added (kg/ha)	Rice	Wheat	Total	Contribution of non-exch. K (kg/ha)	% Contribution
$N_0P_0K_0$	$N_0P_0K_0$	344	332	Nil	161	41	202	190	94.0
N_{120}	N_{120}	342	310	Nil	282	173	455	423	92.9
$N_{120}P_{22}$	$N_{120}P_{22}$	350	304	Nil	344	189	533	487	91.3
$N_{120}P_{22}$	N_{120}	353	315	Nil	321	190	511	473	92.5
N_{120}	$N_{120}P_{22}$	342	314	Nil	329	189	518	490	94.5
$N_{120}P_{22}K_{42}$	$N_{120}P_{22}K_{42}$	411	482	168	347	204	551	454	82.3
$N_{120}P_{22}K_{42}$	N_{120}	389	416	84	337	191	528	471	89.2
N_{120}	$N_{120}P_{22}K_{42}$	392	426	84	337	194	531	481	90.5

deficiency symptoms which were quite marked till 40 days after transplanting

Effect of K on yield, K content and uptake

Application of K had no effect on the yields of rice and wheat (Table 2). Application of K fertilizer brought about improvement in its available status only by 16.0 to 34.4% over the initial status indicating greater fixation of applied K in these soils. After the harvest of 20 crops and in spite of a substantial K uptake, the available K status went down only slightly (12.0 to 24.2 ppm) in the treatments which did not receive K fertilizer (Table 7). The clay minerals present in these soils are predominantly illitic having high K content and hence the K release from such minerals during cropping periods might have been sufficient to meet the crops requirement. Swarup and Ghosh[11] also did not observe any significant effect of K fertilizer on grain yield of wheat. As regards the removal of K by rice and wheat it was seen that application of N and P increased the K uptake over the control. Single application of N enhanced the K uptake nearly two fold. Rice was more exhaustive than wheat in respect of K removal (Table 6). The total K removal by 4 crops (Table 6) was 455, 533 and 551 kg/ha in N, NP and NPK treatments (No. 2, 3 and 6) respectively. The contribution of non-exchangeable K towards total K uptake of crops was worked out using the following relationship:

K uptake from non-exchangeable form = Total K uptake by plants + available K after Cropping – Fertilizer K added – Available K before cropping.

It was observed that in plots receiving no fertilizer K for the last 10 years, the contribution of non-exchangeable K to total uptake was about 93% whereas K application reduced it to about 87% (Table 6). The results are in close conformity with the findings of Singh and Ghosh[9]. This also implies that continuous cropping with high levels of N and P would result in a gradual depletion of K reserves thereby rendering the soils responsive to K in time to come. With addition of 168 kg K/ha (cumulative) during the period under study (1982–83 and 83–84), the K uptake increased over the respective no K treatment (Table 6). This however, was not due to high dry matter yield but implied a luxury consumption of K following its application (Table 5). The concentration of K in the grains of both crops remained unaffected but in straw it increased significantly (Table 5) as also reported by Swarup and Ghosh[10]. In both the crops N application enhanced the K concentration in straw. While the requirement of crops has been met mainly from non-exchangeable K of the soil, the rate of attainment

Table 7. Changes in available P and K status of sodic soil in rice wheat sequence

Treatment		Available P (ppm)						Available K (ppm)	
		After 1982 rice		After 1983 rice		After 1983–84 wheat		After 1983 rice	After 1983–84 wheat
Rice	Wheat	0–15 cm	15–30 cm	0–15 cm	15 30 cm	0–15 cm	15–30 cm	0–15 cm	0–15 cm
$N_0P_0K_0$	$N_0P_0K_0$	10.8	11.5	8.9	10.2	8.4	9.8	150.6	148.0
N_{120}	N_{120}	5.5	7.0	4.8	6.8	4.5	6.2	145.3	138.6
$N_{120}P_{22}$	$N_{120}P_{22}$	20.6	36.1	25.6	35.4	28.6	35.0	141.6	135.8
$N_{120}P_{22}$	N_{120}	15.8	26.8	20.1	26.4	21.7	25.7	148.5	140.7
N_{120}	$N_{120}P_{22}$	14.5	27.0	19.8	25.7	20.8	24.8	142.3	140.2
$N_{120}P_{22}K_{42}$	$N_{120}P_{22}K_{42}$	21.6	38.4	25.8	38.0	27.8	37.5	210.8	215.1
$N_{120}P_{22}K_{42}$	N_{120}	14.9	25.8	20.5	25.2	21.4	24.7	190.5	185.7
N_{120}	$N_{.20}P_{22}K_{42}$	15.5	26.2	20.1	25.7	20.9	25.0	192.4	190.0
C.D. (0.05)		3.1	5.0	4.2	5.2	3.8	4.8	16.5	16.0

Table 8. Release of K by repeated washings with 1 *N* NH_4OAC pH 7.0 (ppm)

Treatment		Number of extraction					
Rice	Wheat	1	2	3	4	5	Total
$N_0P_0K_0$	$N_0P_0K_0$	148.0	65.0	33.8	23.7	18.7	289.2
N_{120}	N_{120}	138.6	63.7	37.5	27.4	22.5	289.7
$N_{120}P_{22}$	$N_{120}P_{22}$	135.8	55.0	32.5	21.2	20.0	264.5
$N_{120}P_{22}$	N_{120}	140.7	50.0	28.7	21.2	18.7	259.3
N_{120}	$N_{120}P_{22}$	140.2	55.0	28.0	22.5	16.9	262.6
$N_{120}P_{22}K_{42}$	$N_{120}P_{22}K_{42}$	215.1	72.5	37.5	27.8	23.7	376.6
$N_{120}P_{22}K_{42}$	N_{120}	185.7	78.2	38.7	27.5	23.8	353.9
N_{120}	$N_{120}P_{22}K_{42}$	190.0	67.5	35.0	25.4	20.8	338.7

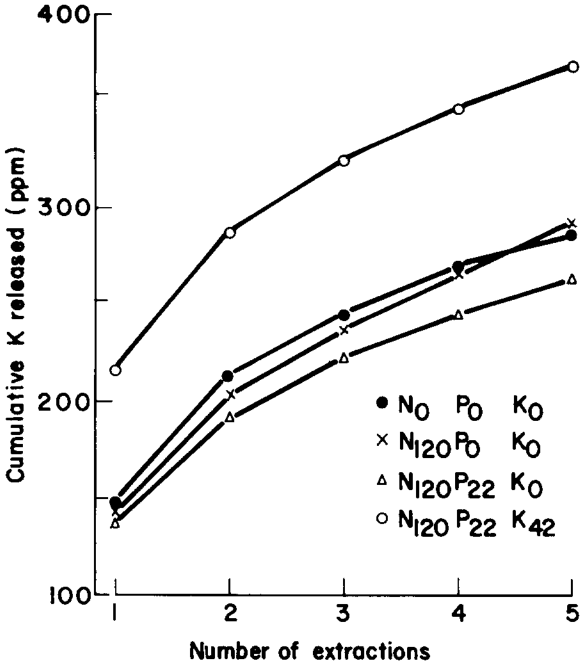

Fig. 1. Relationship between K release and number of extractions.

of equilibria of K from one form to other seems to be quite rapid to fulfil the plants requirement. Since the available K in various plots after cropping varied from 304 to 482 kg K/ha it appeared important to study their K supplying capacity (Table 8). The cumulative K release was maximum in plots receiving K fertilizer, it was minimum in plots receiving no K. Data in Table 8 show that upto 5th extraction sufficient quantity of K was desorbed. Plot of cumulative K release *vs* number of extractions (Fig. 1) for some selected treatments revealed that the major difference in the ammonium acetate extractable K was only in the first extraction (mainly the exchangeable K fraction). Thereafter, the curves ran parallel to each other indicating that after removal of K in the first extraction subsequent release was independent of the available K and it was mainly a function of the nature and quantity of the clay mineral present in the soil.

From the above study it could be concluded that continuous cropping for 10 years in no way depleted available K in soil to a level where plants either rice or wheat or both could suffer K deficiency. Non-exchangeable pool of soil K has mainly accounted for the utilization of K by the crops. These soils could still be cropped without K fertilization. However, there is a strong need to characterise the various processes/mechanisms which control the release of non-exchangeable K to exchangeable form.

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