Effect of Long-term Rice-Wheat Cropping Sequence on Yield and Soil Properties in a Reclaimed Sodic Soils

K N Singh and Anand Swarup[1]

Abstract

In a field experiment initiated in 1974 on a sodic soil continuous cropping with rice and wheat grown in rotation from 1974/75 to 1994/95 (except from 1986 to 1993 when rice was replaced with pearl millet during rainy season) reduced available N, P, and K in unfertilized plots (control). Continuous use of fertilizer N alone (120 kg N ha^{-1}) or in combination with P and K significantly enhanced yield of crops and available N. Phosphorus applied at a rate of 22 kg P ha^{-1} to either or both rice and wheat in rotation significantly improved yields of rice and wheat from 1979 and 1985/86 onwards respectively. Where N alone was applied, available P and K declined. Potassium applied at the rate of 42 kg K ha^{-1} to either or both crops had no effect on yields. Application of N, P, and K enhanced concentration and uptake of these elements in the crops. Continuous cropping for 21 years reduced soil pH from 9.2 to 8.2 and exchangeable sodium percentage (ESP) from 32 to 8.

Introduction

Sodic or alkali soils occur extensively in the Indo-Gangetic alluvial plains of northern India and in several other parts of the world. An excess of exchangeable sodium, high pH, and adverse soil physical properties characterize these soils. Efforts are being made to bring these soils under cultivation through application of amendments, preferably gypsum, and adoption of rice (*Oryza sativa* L.)-based cropping sequence (Abrol and Bhumbla 1979; Oster 1982; Swarup 1985a; Swarup and Singh 1989). Rice is a suitable and popular rainy season crop grown during the initial years of sodic soil reclamation because of its high tolerance of sodium and reclaiming effect (McNeal et al. 1966; Chhabra and Abrol 1977; Swarup 1985b), followed by wheat (*Triticum aestivum* L.) in winter (*rabi* or postrainy season). Apart from reclamation, fertilization of crops assumes an important role since sodic soils are poor in fertility (Swarup 1987).

Uncultivated sodic soils contain very low amounts of organic matter and available nitrogen (N) and high amounts of $NaHCO_3$ extractable phsophorus (P) and ammonium acetate-extractable potassium (K). Long-term studies involving crop responses to N, P, and K fertilization in sodic soils are meager. The present long-term field experiment was designed to: (i) determine the effect of continuous use of N, P, and K on rice and wheat; (ii) explore possibility of reducing use of P and K to either of these crops; and (iii) monitor the changes in available N, P, and K in soil as a result of continuous cropping and fertilizer use, in a partially reclaimed sodic soil.

Materials and Methods

A long-term fertilizer experiment with rice-wheat sequence in the field was initiated in 1974 on a

1. Central Soil Salinity Research Institute, Karnal 132 001, Haryana, India.

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partially reclaimed sodic soil taxonomically classified as an Aquic Natrustalf at the Central Soil Salinity Research Institute (CSSRI), Karnal, India (Table 1). The experiment is being continued in a fixed layout. Karnal is located at 29°N and 76°E and at an elevation of 245 m above mean sea level. The climate of Karnal is semi-arid with an average annual rainfall of 766 mm. The mean annual average maximum temperature is 30°C and minimum temperature is 17°C. The mean monthly maximum temperature is highest during May and lowest during January. The corresponding highest and lowest mean monthly minimum temperature has been recorded during July and January, respectively. The average relative humidity value is lowest (32%) during May and highest (87%) during September.

Nitrogen, P, and K were applied at 100 kg N ha^{-1}, 22 kg P ha^{-1}, and 42 kg K ha^{-1}, in 8 treatment combinations (Table 2). The experiment was laid out in a randomized block design with 4 replications and a gross plot of 6 m × 4 m. The N rate was raised from 100 to 120 kg ha^{-1} for rice from 1978 onwards.

Rice cv IR 8-68 was grown from 1974 to 1979 and cv Jaya from 1980 onwards during wet season. From the beginning of *kharif* (rainy season) 1986 pearl millet (*Pennisetum glaucum* (L.) R. Br.) replaced rice in cropping sequence. Again pearl millet was replaced with rice cv Jaya from *kharif* 1994 onwards. Thirty to 35-day-old rice seedlings were transplanted during the last week of June or first week of July every year at a spacing of 20 cm between rows and 15 cm within rows. Wheat was sown during first/second week of November at a row spacing of 20 cm. Sowing was done with a hand plow @ 100 kg seed ha^{-1}. Pearl millet BK 560 was sown in the first week of July at a row spacing of 50 cm. In pearl millet, thinning was done 20 days after sowing to maintain a spacing of 15 cm between plants within a row. Half the dose of N and full dose of P and K was given at the transplanting of rice and at the sowing of wheat/pearl millet. The remaining dose of N was top dressed in two equal splits when crops were 3 and 6 weeks old. The sources of N, P, and K were urea, single superphosphate, and muriate of potash respectively. Crops were irrigated with tube well

Table 1. Properties of soil in the experimental field at the Central Soil Salinity Research Institute, Karnal, India.

Mechanical analysis	Value
Sand (%)	51.6
Silt (%)	24.3
Clay (%)	24.1
Soil pH (1:2 soil-water suspension)	9.2
Exchangeable sodium percentage	32.0
Cation exchange capacity (meq $100g^{-1}$)	8.8
Calcium carbonate (%)	2.8
Organic carbon (%)	0.3
Available nitrogen (kg ha^{-1})	225.0
Available phosphorus (kg ha^{-1})	33.6
Available potassium (kg ha^{-1})	358.0

Table 2. **Effect of continuous cropping and fertilizer use on grain yield (t ha^{-1}) of rice (rough) and wheat on a sodic soil at Karnal, India.**

Treatment[1]		Rice			Wheat		
Rice	Wheat	1974	1985	1994	1974/75	1985/86	1994/95
Control	Control	3.81	3.17	2.63	0.84	0.78	1.26
N	N	6.64	4.73	4.45	4.11	4.00	3.10
NP	NP	6.56	6.92	5.54	3.71	4.73	4.33
NP	N	6.63	6.97	5.62	4.14	4.62	3.98
N	NP	7.17	6.47	4.96	3.90	4.89	4.04
NPK	NPK	7.08	6.97	5.46	4.05	4.58	4.41
NPK	N	6.45	6.88	5.27	4.02	4.32	3.96
N	NPK	6.85	6.45	4.96	4.14	4.28	4.14
LSD (P=0.05)		0.96	0.55	0.65	0.82	0.36	0.45

1. Nitrogen (N), phosphorus (P), and potassium (K) were applied at 100 kg N ha^{-1}, 22 kg P ha^{-1}, and 42 kg K ha^{-1}.

water (electrical conductivity 0.3 dS m^{-1}) as and when required. Submerged condition (5±2 cm standing water above soil) were maintained during growth period of rice. Weeds were removed manually. Rice was harvested in October and wheat in April, from a net plot of 5.7 m × 3.6 m. Grain yield of rice (rough) was computed at 14% moisture content and straw yield on oven-dry basis. In wheat, both grain and straw yield were recorded on an air-dry basis. Pearl millet was harvested in October from a net plot of 3 m × 5 m.

Composite soil samples (0–15 and 15–30 cm depth) were collected from each plot with a 5-cm diameter auger after harvest of wheat, and were ground to pass through a 2-mm sieve and analyzed. Available N was determined according to the method of Subbiah and Asija (1956). The available K (water-soluble + exchangeable) was extracted with 1 N ammonium acetate at pH 7.0 and measured with a flame photometer (Jackson 1967). Available P was extracted with 0.5 M $NaHCO_3$ at pH 8.5 according to Olsen et al. (1954). Soil pH was measured in 1:2 soil-water suspension. Other soil properties were determined using standard methods (Jackson 1967). Grain and straw samples of rice and wheat were wet-digested in di-acid mixture (3 HNO_3:1 $HClO_4$) and analyzed for P and K. Phosphorus was determined by vanado-molybdophosphoric acid yellow-color method, and K by flame photometry. For N measurements, plant material was digested separately and analyzed with a Kjeltec Auto 1030 Analyzer.

Results and Discussion

Grain yield

Nitrogen application alone significantly enhanced grain yield of rice and wheat (Figs. 1 and 2; and Table 2). Nitant and Dargan (1974), Singh and Sharma (1984), and Kumar et al. (1995) also reported high crop responses to N in sodic soils. Phosphorus application to either one or both the crops significantly enhanced grain yield of rice after 1978, when available P in the upper 0–15 cm soil depth had fallen to 12.7 kg P ha^{-1}, which is very close to widely used critical soil test value of 11.2 kg P ha^{-1} (Olsen et al. 1954).

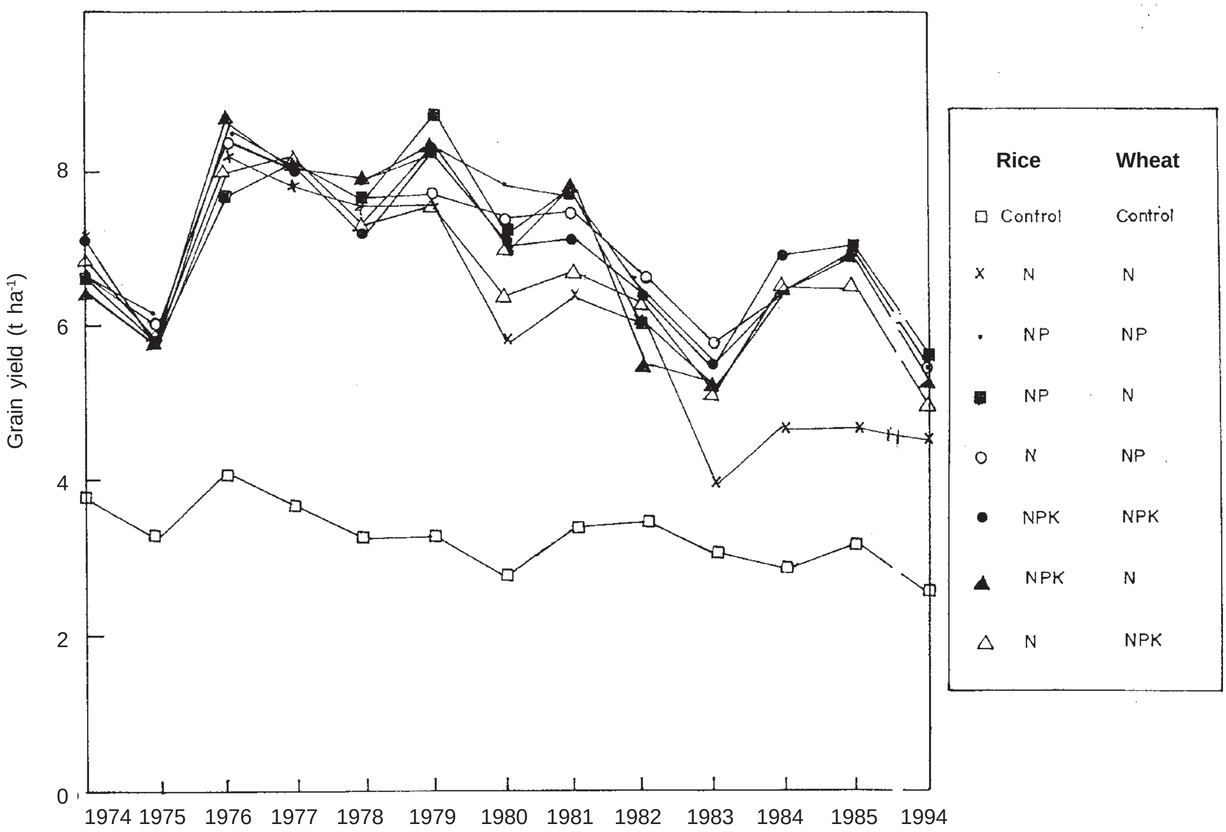

Figure 1. Effect of fertilizer treatments on grain yield of rice in rice-wheat sequence at Karnal, India.

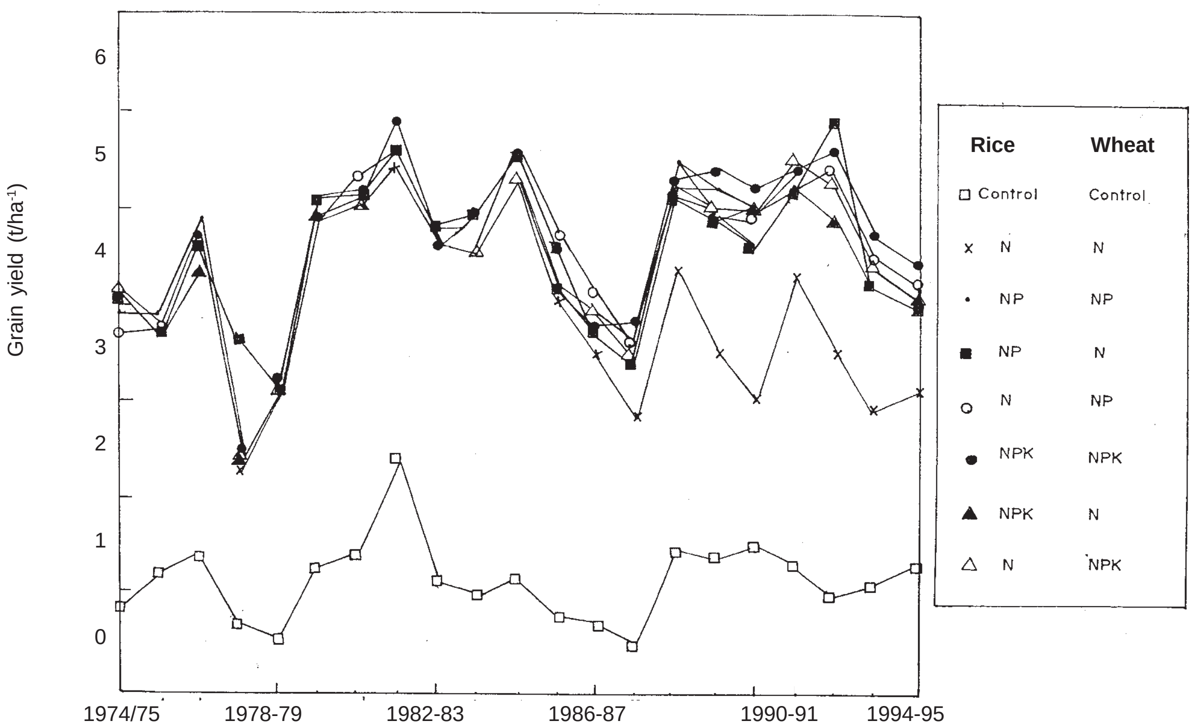

Figure 2. Effect of fertilizer treatments on grain yield of wheat in rice-wheat sequence at Karnal, India.

Phosphorus application had no effect on yields in the first 5 years (1974–78), as the soil had high amounts of P. Wheat did not respond to P application for 11 years because soil at low depths (15–30 cm) had a high amount of available P, which had not yet declined to critical level. Wheat roots grow deep into the soil (Krishnamoorthy and Venkateswarlu 1976). Wheat responded to applied P only during 1985/86 when available P fell to 8.7 kg ha^{-1} in the 0–15 cm soil depth and close to critical level (11.6 kg ha^{-1}) in 15–30 cm depth. Effect of K application on yields was not significant (Table 2). Lack of crop responses to applied K in these soils is attributed to high available K status and large reserve of K in the soils.

In general, wheat yield improved over years as a result of decrease in soil pH and exchangeable sodium percentage (ESP), except in 1977/78 and 1978/79 when hailstorms occured during the growing season and damaged the crops. There were variations in rice yields from year to year. Obviously, factors other than soil properties studied have influenced yield trends. Rice yields are often better when there is a good rainfall during the growing season. Yields of pearl millet were also enhanced with fertilizer application during 1986–93 (Table 3).

Nutrient concentration and uptake

Nitrogen application alone or in combination with P and K significantly enhanced concentration of N in grain and straw of rice and wheat over control (Tables 4, 5, and 6). Improvement in N content of rice and wheat with P application indicated a favorable influence of P on N nutrition (Swarup and Ghosh 1984). Phosphate fertilization significantly enhanced P concentration of both crops irrespective of its effect on yields (Chhillar and Swarup 1984). The P content of rice and wheat, reduced significantly when only N was applied (Tables 4 and 5), showing inadequate amount of P in soil and consequently its lesser uptake by crops. However, P uptake was higher in fertilizer treatments than control because of high dry matter production (Table 6). Application of P to either or both rice and wheat significantly

Table 3. Effect of continuous cropping and fertilizer use on grain yield of pearl millet on a sodic soil at Karnal, India.[1]

Treatment[2]		Grain yield (t ha^{-1})					
Rice	Wheat	1986	1987	1989	1991	1992	1993
Control	Control	0.54	0.70	0.65	0.54	0.91	1.16
N	N	1.47	1.39	1.45	1.89	1.92	2.18
NP	NP	1.80	1.65	1.72	2.17	2.34	2.04
NP	N	1.80	1.58	1.68	2.00	5.34	2.18
N	NP	1.73	1.54	1.65	1.99	2.43	2.33
NPK	NPK	2.02	1.68	1.85	2.77	2.55	2.33
NPK	N	1.95	1.67	1.80	2.04	2.52	2.45
N	NPK	1.91	1.60	1.78	1.97	2.40	2.42
LSD (P=0.05)		0.35	0.30	0.34	0.30	0.52	0.43

1. In rice-wheat cropping system, rice was replaced by pearl millet during 1986–93.

2. Nitrogen (N), phosphorus (P), and potassium (K) were applied at 100 kg N ha^{-1}, 22 kg P ha^{-1}, and 42 kg K ha^{-1}.

Table 4. Effect of continuous cropping and fertilizer use on nutrient content in rice grown in sodic soil in rice-wheat system in 1994 at Karnal, India.

Treatment[1]		N (%)		P (%)		K (%)	
Rice	Wheat	Grain	Straw	Grain	Straw	Grain	Straw
Control	Control	0.86	0.35	0.283	0.030	0.34	1.45
N	N	1.30	0.42	0.275	0.028	0.33	1.50
NP	NP	1.35	0.45	0.362	0.036	0.36	1.55
NP	N	1.33	0.43	0.358	0.035	0.35	1.54
N	NP	1.31	0.41	0.349	0.035	0.35	1.52
NPK	NPK	1.36	0.46	0.368	0.037	0.40	1.70
NPK	N	1.35	0.46	0.365	0.036	0.39	1.68
N	NPK	1.33	0.45	0.362	0.036	0.39	1.66
LSD (P=0.05)		0.07	0.05	0.040	0.004	0.05	0.10

1. Nitrogen (N), phosphorus (P), and potassium (K) were applied at 100 kg N ha^{-1}, 22 kg P ha^{-1}, and 42 kg K ha^{-1}.

Table 5. Effect of continuous cropping and fertilizer use on nutrient content of wheat grown in sodic soil in rice-wheat system during 1994/95 at Karnal, India.

Treatment[1]		N (%)		P (%)		K (%)	
Rice	Wheat	Grain	Straw	Grain	Straw	Grain	Straw
Control	Control	1.27	0.40	0.342	0.036	0.32	1.36
N	N	1.57	0.48	0.305	0.034	0.31	1.34
NP	NP	1.68	0.51	0.372	0.043	0.34	1.40
NP	N	1.65	0.49	0.352	0.041	0.34	1.38
N	NP	1.66	0.50	0.358	0.041	0.33	1.39
NPK	NPK	1.70	0.52	0.366	0.043	0.36	1.56
NPK	N	1.66	0.50	0.354	0.041	0.35	1.52
N	NPK	1.77	0.51	0.360	0.042	0.36	1.54
LSD (P=0.05)		0.10	0.05	0.032	0.045	0.03	0.08

1. Nitrogen (N), phosphorus (P), and potassium (K) were applied at 100 kg N ha^{-1}, 22 kg P ha^{-1}, and 42 kg K ha^{-1}.

increased uptake of N, P, and K by the crops in comparison to treatments in which P was not applied. The concentration of K in grain and straw of crops increased significantly following its application. Although N and P application had a positive effect on K concentration, it was not significant. Rice was more exhaustive than wheat in terms of N, P, and K removal (Table 6).

Soil properties

Continuous cropping for 20 years reduced available N from initial level of 225 kg ha^{-1} to 103 kg ha^{-1} in unfertilized plots. However, continuous use of fertilizer N alone or in combination with P and K either maintained or slightly increased available N with final values ranging from 235 kg ha^{-1} to 248 kg ha^{-1}. With

Table 6. Effect of continuous cropping and fertilizer use on total (grain + straw) nutrient uptake by rice and wheat in rice-wheat system during 1985/86 at Karnal, India.

Treatment[1]		Uptake (kg ha^{-1}) by rice			Uptake (kg ha^{-1}) by wheat		
Rice	Wheat	N	P	K	N	P	K
Control	Control	39.4	8.9	78.5	24.4	5.1	32.6
N	N	86.8	14.2	118.2	70.3	11.0	69.9
NP	NP	108.5	22.8	136.1	101.8	18.6	94.5
NP	N	107.4	22.8	136.8	89.7	16.0	81.2
N	NP	93.7	19.8	123.8	93.6	16.6	87.0
NPK	NPK	110.1	23.0	154.4	102.0	18.4	97.0
NPK	N	105.2	21.9	144.9	90.7	16.1	89.9
N	NPK	97.0	20.4	133.8	99.8	17.1	95.0
LSD (P=0.05)		8.5	4.0	9.4	7.0	3.0	8.2

1. Nitrogen (N), phosphorus (P), and potassium (K) were applied at 100 kg N ha^{-1}, 22 kg P ha^{-1}, and 42 kg K ha^{-1}.

regular P application to crops in sequence the available P increased from initial value of 33.6 kg ha^{-1} to 58.0 in NP-NP and to 57.6 kg ha^{-1} in NPK-NPK, in the 0–15 cm soil depth (Table 7). Treatments which supplied P to either rice or wheat in rotation did not have significant effects and led to only marginal improvement (Table 3). Where N alone was applied, available P declined progressively to 4.0 kg ha^{-1} from initial 33.6 kg ha^{-1} (Table 7). This may be a result of enhanced dry matter production and consequent higher uptake of P by crops (Table 6). Potassium applied to either or both crops in rotation increased available K to 560, 476, and

Table 7. Effect of continuous cropping and fertilizer use on available nutrients in the surface soil during 1994 at Karnal, India.[1]

Treatment[2]		Available nutrient[3] (kg ha^{-1})		
Rice	Wheat	N	P	K
Control	Control	103	9.8	213
N	N	235	4.0	193
NP	NP	243	58.0	198
NP	N	240	15.6	193
N	NP	240	16.9	203
NPK	NPK	245	57.6	560
NPK	N	240	15.2	476
N	NPK	237	15.8	483
CD (P=0.05)		13	5.4	19

1. Estimated after harvest of wheat, 1993/94 in surface soil at 0–5 cm depth.
2. Nitrogen (N), phosphorus (P), and potassium (K) were applied at 100 kg N ha^{-1}, 22 kg P ha^{-1}, and 42 kg K ha^{-1}.
3. Initial values in 1974 were 225 kg N ha^{-1}, 33.6 kg P ha^{-1}, and 358 kg K ha^{-1}.

483 kg ha^{-1} in NPK-NPK, NPK-N, and N-NPK treatments from the initial 358 kg ha^{-1} (Table 7). After harvest of 40 crops, and in spite of a substantial K uptake, available K declined during cropping periods. Final values ranged from 193 kg ha^{-1} to 203 kg ha^{-1} in treatments that did not receive K fertilizer (Table 7). It seems that continuous cropping for 20 years in no way depleted available K in soil to a level where either rice or wheat or both could suffer K deficiency. This may be attributed to the fact that exchangeable K levels were maintained by equilibrium with non-exchangeable pool of soil K (Swarup and Chhillar 1986).

There was a noticeable decline in soil pH and ESP as a result of continuous cropping, but no differential effect was observed due to various treatments. The drop in pH and ESP was sharp in first 3 years, gradual for next 5 years and afterwards (1982/83 onwards) remained almost constant at 8.2 (Figs. 3 and 4). Continuous cropping for 21 years decreased ESP from initial level of 32 to 8 and soil pH from 9.2 to 8.2 in 0–15 cm soil depth. However, at lower depths soil pH and ESP, though decreased progressively, were still higher than initial values of surface soil (0–15 cm). A considerable improvement in sodic soil was brought about by rice rather than wheat grown in sequence (Swarup and Singh 1989). The soil pH and ESP of 0–15 cm soil were also not affected with the inclusion of pearl millet in cropping sequence from 1986 to 1993 in place of rice.

Conclusion

The study suggests that 120 kg N ha^{-1} should be applied to both rice and wheat to get optimum yields in reclaimed sodic soils. Phosphorus at the rate of 22 kg P ha^{-1} should be given to rice only when available P (Olsen's extractable) in top 15 cm soil depth has come down to 12.7 kg P ha^{-1}. There is no need to apply K in these soils since they contain high available K and there occurs large contribution of non-exchangeable K towards total K uptake by crops.

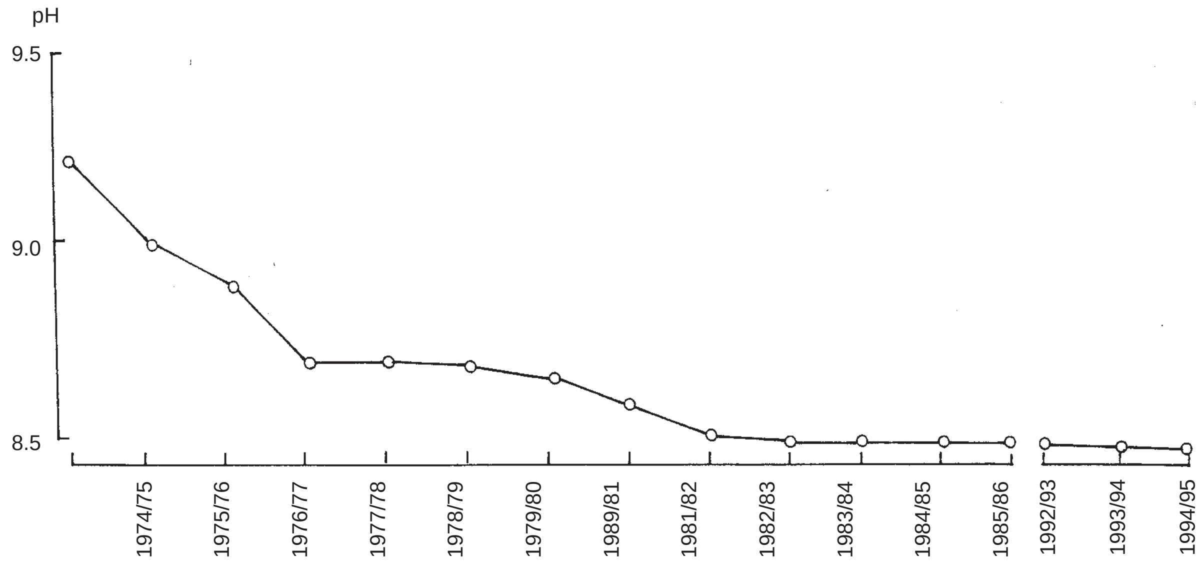

Figure 3. Effect of rice-wheat sequence on pH of soil during 1974–95 at Karnal, India.

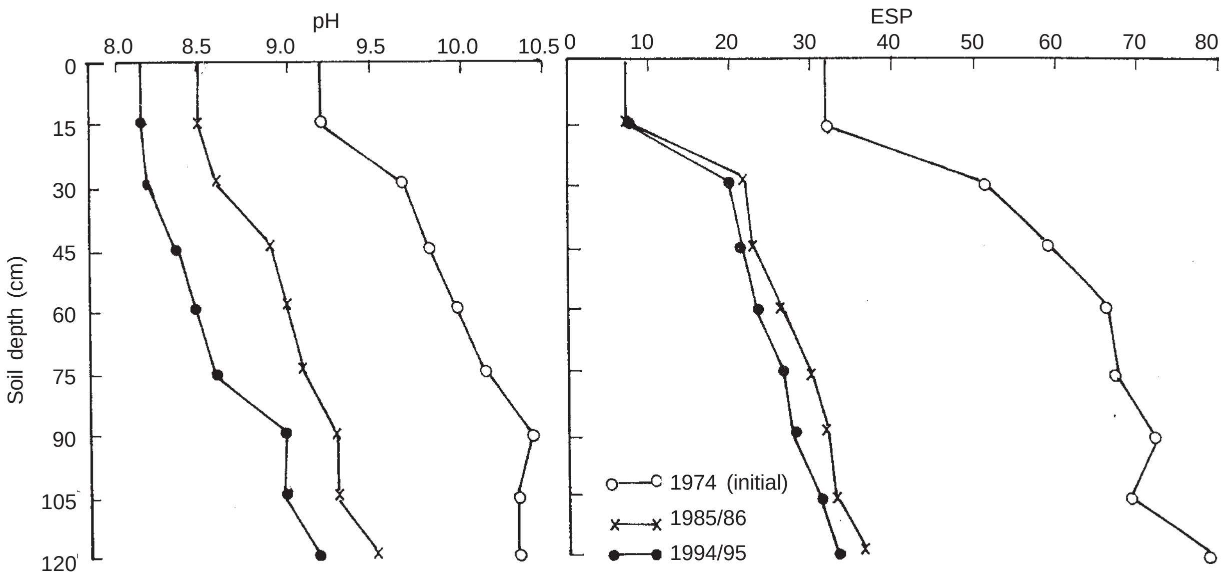

Figure 4. Effect of rice-wheat cropping on pH and exchangeable sodium percentage (ESP) of sodic profile of soil at Karnal, India.

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