Effects of Long-term Jute-Rice-Wheat Cropping System on Crop Yields and Soil Fertility

M N Saha, A R Saha, B C Mandal, and P K Ray[1]

Abstract

Changes in soil properties and crop productivity as affected by long-term fertilization for 25 years in the New Gangetic alluvial soil (Eutrochrept) with jute-rice-wheat cropping sequence was investigated. In general a decreasing trend in jute, rice, and wheat yields was observed. Highest response in fiber and grain yields was obtained with 150% NPK (nitrogen, phosphorus, potassium). Effect of FYM (farmyard manure) was perceptible in jute as well as in the succeeding crops of rice and wheat. Application of sulfur (S)-free fertilizers had an adverse effect on rice yield. Rice responded more to applied N and P whereas jute responded more to applied K. Uptake of N was found highest in rice whereas uptake of P and K by wheat was less in comparison to jute and rice. Build-up in N, P, K, and S content was reflected in soil test values. Available soil P and S declined in control as well as in P and S-free treated plots. A general decline in organic carbon and available zinc and an increase in available iron was observed in all plots.

Introduction

Availability of modern fertilizer-responsive high-yielding crop varieties has led to their wide adoption and farmers are using high doses of fertilizers to get high yields. Continuous application of fertilizers at high doses may, however, have an adverse effect on crop yields and physical, chemical, and microbiological soil properties. It was, therefore, considered important to initiate a long-term manurial experiment in West Bengal, India with a commonly practiced cropping sequence of the region, i.e., jute (*Corchorus capsularis* L.)-rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.).

Materials and Methods

A permanent field trial was laid out in 1971 at the Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India, with jute (JRO 632 and JRO 7835)-rice (Jaya and Ratna)-wheat (Sonalika) cropping sequence under the All India Coordinated Research Project on Long-term Fertilizer Experiment. This site is located between 88°26' E and 22°45' N and at an altitude of 9 m above sea level. On an average over 25 years, the area received about 1,666 mm rainfall annually spread over 110 days per year. The average maximum and minimum atmospheric temperatures were 31.1°C and 20.8°C. Both morning and evening average soil temperatures at 30 cm soil depth were recorded as 27°C . The average relative humidity was 93.9% in the morning and 57.8% in the evening.

The site, irrigated with turbine pump, had a water table at 6.6 m depth in rainy season and 10 m depth in summer. The soil of the experimental field was described as Eutrochrept (Nilganj series). The experiment was laid out in a randomized block design with 4 replications. The treatments included (i) 50% of

1. Central Research Institute for Jute and Allied Fibres, Barrackpore, North 24 Parganas, West Bengal 743 101, India.

Saha, M.N., Saha, A.R., Mandal, B.C. and **Ray, P.K.** 2000. Effect of Long-term Jute-Rice-Wheat Cropping System on Crop Yields and Soil Fertility. Page 94–104 *in* Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems (Abrol, I.P., Bronson, K. F., Duxbury, J. M. and Gupta, R. K. eds.). Rice-Wheat Consortium Paper Series 6. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

recommended dose of NPK (nitrogen, phosphorus, potassium), (ii) 100% NPK, (iii) 150% NPK, (iv) 100% NPK with hand weeding, (v) 100% NPK with ZnSO4 @ 10 kg ha^{-1} added in wheat only, (vi) 100% NP, (vii) 100% N, (viii) 100% NPK with farmyard manure (FYM) @ 10 t ha^{-1} in jute only, (ix) 100% NPK as sulfur (S)-free treatment, and (x) control plots. The 100% dose of NPK was 120-26-50 kg ha^{-1} for wheat and rice and 60-13-50 kg ha^{-1} for jute. The sources of N and P in S-free treatment were urea and diammonium phosphate respectively. Unless otherwise stated sources of N, P, and K were urea (ammonium sulfate up to 1989), single superphosphate, and muriate of potash respectively. The area of each individual plot was 200 m^2 (20 m × 10 m). The experiment was started in 1971 without any control but this was included in 1972.

Soil (0–22.5 cm) and plant samples were collected after each crop and analyzed following standard procedures (Jackson 1967) for their physical and chemical analyses. Soil samples were collected from each plot and composite soil samples were prepared by quartering method. The initial composite soil samples (0–22.5 cm) were also analyzed. The soil was sandy loam (54% sand, 28% silt, and 18% clay) with illitic mineralogy and pH 7.1 (1:2 soil-water suspension); high in available P (41.5 kg ha^{-1}, Olsen's $NaHCO_3$ method), available N (223.1 kg ha^{-1}, Alk KMnO4 method), and K (142.7 kg ha^{-1}, NH_4OAc), and medium in organic carbon content (0.71%, Walkley and Black method). Other important characteristics of the soil were: 44.3% water-holding capacity, 19.0 c mol kg^{-1} cation exchange capacity (CEC); 1.3 g cm^{-3} bulk density; sticky point 25.1%; pore space 49.4%; and electrical conductivity (EC) 0.23 dS m^{-1}. The total content of N, P, K, silicon (Si), sesquioxides, iron (Fe), calcium (Ca), and magnesium (Mg) were 0.086, 0.1, 0.225, 85.6, 8.25, 4.3, 0.4, and 0.06% respectively.

Results and Discussion

Yield response

The pooled data over the years (1971–95) showed that highest response in jute fiber and grain yield of rice and wheat was obtained with 150% NPK treatment. The yields were 2.25 t ha^{-1} (fiber) in jute, 4.32 t ha^{-1} (grain) in rice, and 2.98 t ha^{-1} (grain) in wheat (Figs. 1, 2, and 3). It was also observed that reduction in the quantum of inputs (50% NPK) and exclusion of one or more nutrient elements (100% NP and 100% N) resulted in significantly lowering of yields of jute, rice, and wheat than 100% NPK treatment. The reduction was 20, 9, and 15% in jute, 24, 3, and 11% in rice, and 25, 5, and 13.5% in wheat at 50% NPK, 100% NP, and 100% N treatments respectively (Figs. 4, 5, and 6). Treatment with 150% NPK increased yield by 6% in jute, 8% in rice, and 25% in wheat. Additional fertilizer input over recommended dose had a considerable impact on wheat yield. Continuous cultivation without adequate manuring adversely affected crop yields and fertility status of soil. Results are in conformation with those of Prasad et al. (1983).

Effect of FYM, S, and zinc on crop yield

The data revealed that FYM applied during jute sowing had little impact on jute and subsequent rice, but the residual effect of FYM was perceptible on wheat yield which increased by 5% over 100% recommended dose of NPK treatment. This confirmed the results of Kanwar and Prihar (1962).

Sulfur-bearing fertilizer (ammonium sulphate and superphosphate) treatments recorded higher yield of jute and rice as compared to S-free

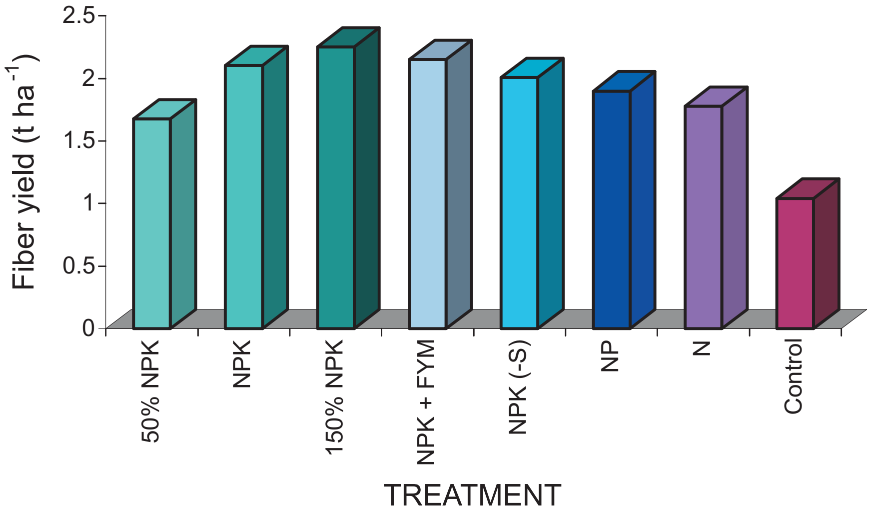

Figure 1. Mean jute fiber yield in different fertilizer treatments during 1971–95 at Barrackpore, India.

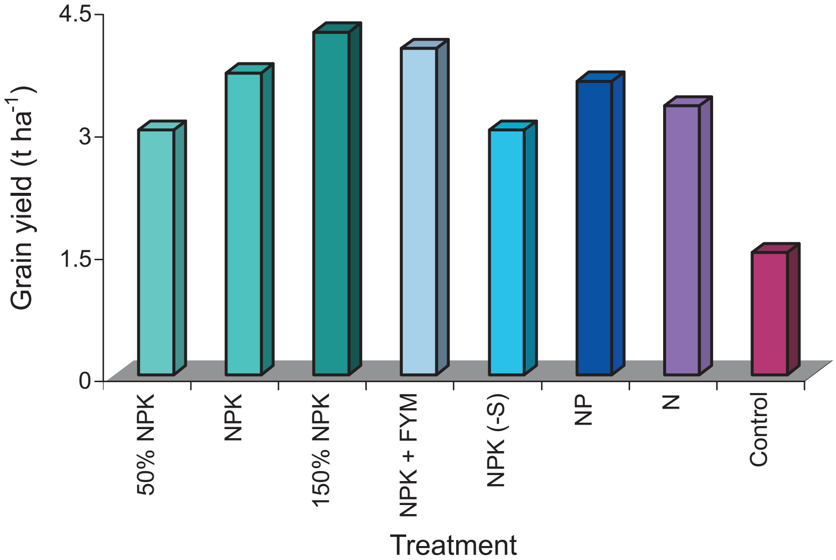

Figure 2. Mean rice grain yield in different fertilizer treatments during 1971–95 at Barrackpore, India.

fertilizer treatments (diammonium phosphate and urea). The increase was 5% in jute and 28% in rice. The requirement of S for rice is almost the same as that of P. Intensive cropping with high-yielding cultivars using large amount of S-free fertilizers over years generally depletes S reserve of soil and thus limits yield potential of the crop. Non-availability of expected increase in rice yields with S-bearing fertilizers may be attributed to possible reduction of sulfate to sulphide, leading to toxicity of plant under highly reduced condition in wetland soils.

Application of zinc (Zn) before sowing of wheat had no significant effect on crop yield. This may be explained from the available status of soil-Zn, which was well above the critical limit (0.5 ppm DTPA extractable).

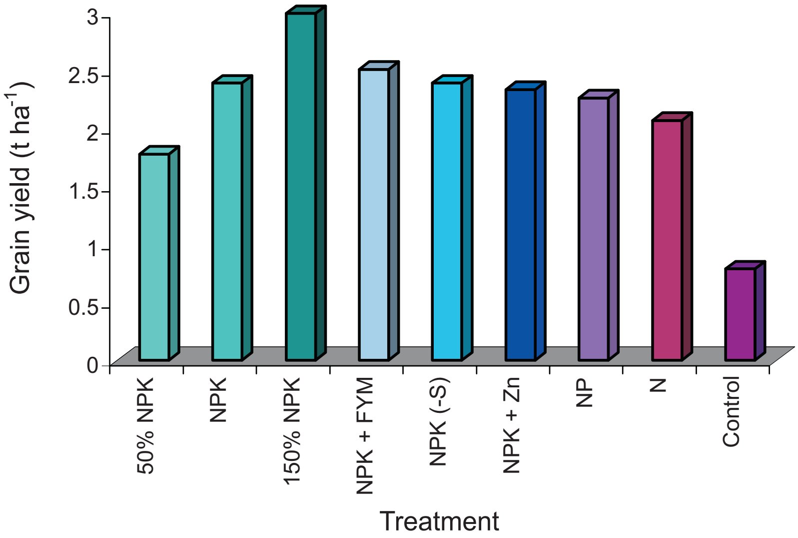

Figure 3. Wheat grain yield in different fertilizer treatments during 1971–95 at Barrackpore, India.

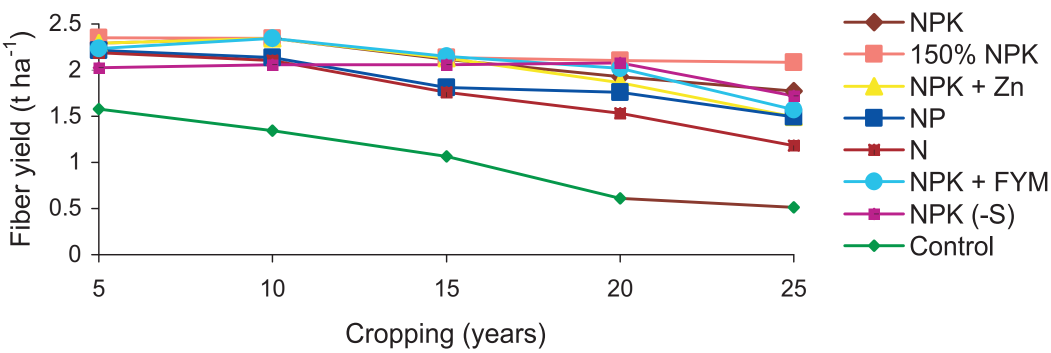

Figure 4. Mean fiber yield of jute in different fertilizer treatments during 1971-95 at Barrackpore, India.

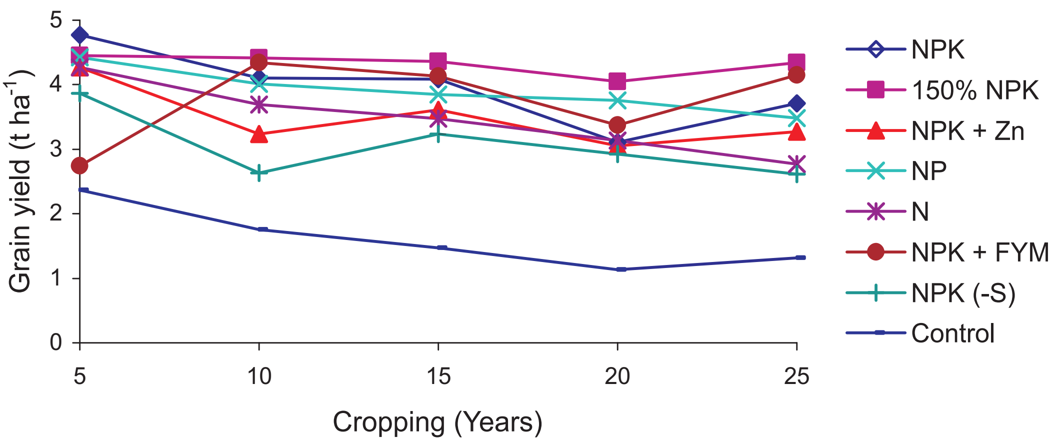

Figure 5. Mean grain yield of rice in different fertilizer treatments during 1971–95 at Barrackpore, India

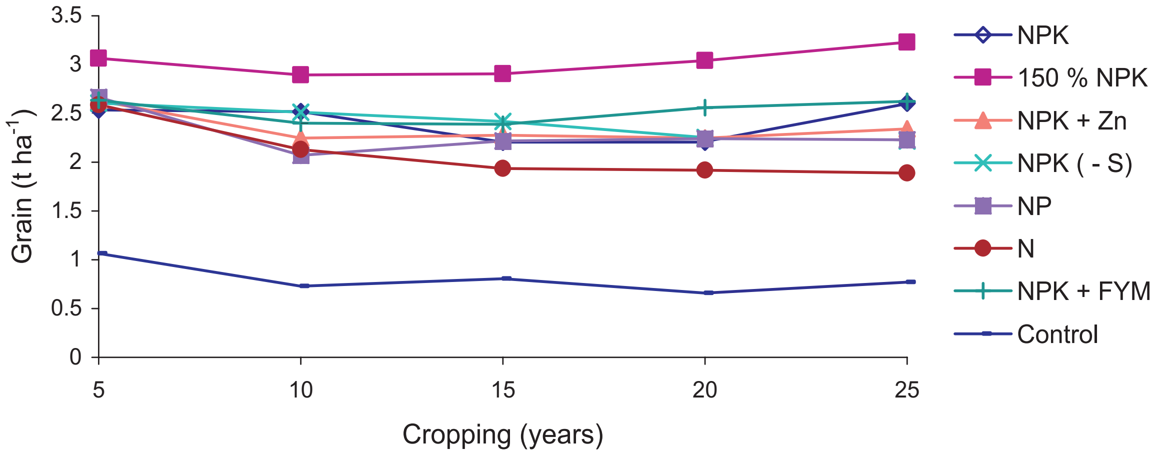

Figure 6. Mean grain yield of wheat in different fertilizer treatments during 1971–95 at Barrackpore, India

Yield trends

Pooled mean yield data of all crops over 25 years showed no regular trend. Yield of rice decreased more distinctly than wheat (Fig. 7). A decreasing trend in jute and wheat yield was manifested. The yield of rice was not so affected which might be due to enriched soil through natural leaf shedding of previously grown jute crop. The year-wise pooled data, showed a distinct decreasing trend in yield of jute, rice, and wheat.

Crop response to nutrient applied

The average response in yield per kg of applied N was 15.5 kg in rice, 12.2 kg in jute, and 10.7 kg in wheat (Table 1). Rice showed maximum response to fertilizer N. A gradual decreasing trend in response was observed in all crops under study. The average yield response per kg of P applied was 16.7 kg in rice, 8.2 kg in jute, and 7.5 kg in wheat. Again, rice responded more to P than wheat and jute. Application of P over years in continuous cropping leads to build-up of P in

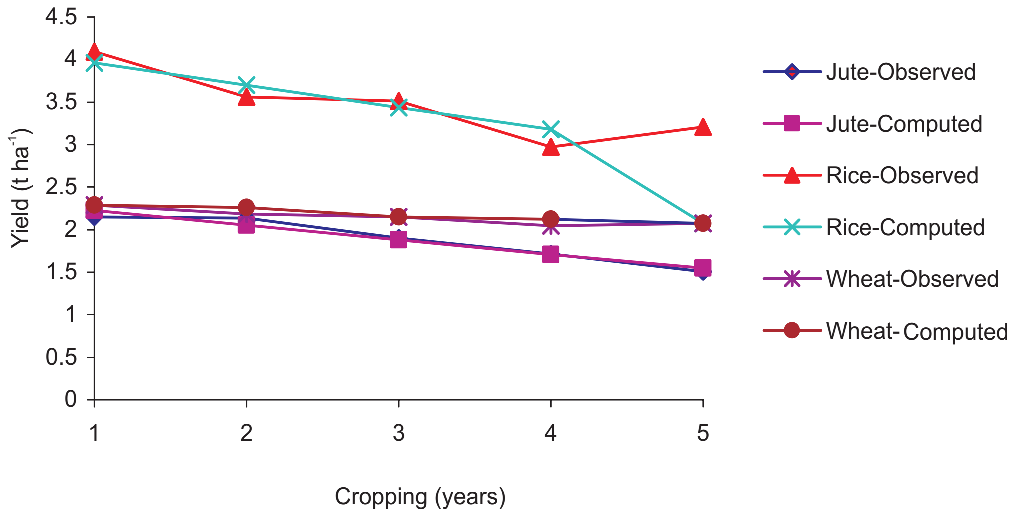

Figure 7. Yield of jute, rice, and wheat irrespective of treatments during 1971–95 at Barrackpore, India.

Table 1. Nutrient response and efficiency in rice-wheat system at Barrackpore, India during 1971–95.

Crop	Yield increase (kg ha^{-1}) due to			Agronomic efficiency[1] (kg)		
	N	P	K	N	P	K
Jute	734	108	208	12.2	8.2	4.2
Rice	1860	435	51	15.5	16.7	2.5
Wheat	1285	195	128	10.7	7.5	2.5

1. Yield per kg of applied nutrients.

soil, but it was not reflected in additional crop yield which was 7.5–6.7 kg kg^{-1} of P applied.

The mean yield kg^{-1} of applied K was 4.2, 2.5, and 2.5 kg for jute, rice, and wheat respectively (Table 1). Jute showed higher response to K application than rice and wheat though, in general, K application induced resistance against disease and pest incidence to some extent to all crops.

Wheat yield was negatively correlated with minimum atmospheric temperature. Rice yield was positively correlated with morning humidity and negatively correlated with minimum atmospheric temperature. Jute yield was negatively correlated with both atmospheric temperature and soil temperature. The yield was significantly reduced when morning subsoil temperature increased above 31.4°C.

Nutrient uptake

For calculating nutrient uptake, leaf, bark, and wood in jute and straw and grain in rice and wheat were considered. Nitrogen uptake was highest (76.3 kg ha^{-1}) in rice, followed by jute and wheat (Table 2). Uptake of P and K was more or less same in rice and jute whereas it was less in wheat. Magnesium and calcium (Ca) uptake by jute was 1.5 to 4 times more as compared to rice and wheat. Amongst micronutrients, Fe uptake was highest (1,334–1,843 g ha^{-1}) in all crops, while uptake of copper (Cu) was the least (13–26 g ha^{-1}). Rice removed more manganese (Mn) (620 g ha^{-1}) than jute and wheat, but all crops removed more or less similar quantity of Zn (233–291 g ha^{-1}).

Nutrient balance and soil studies

Addition of NPK fertilizers even at the lowest level (50% NPK) manifested a positive balance of N and P which showed an increasing trend with increasing level of NPK fertilizers (Table 3). This may be due to low yield levels and low nutrient uptake particularly of wheat. On the other hand, negative balance for K was observed even at the highest level of applied fertilizers (150% NPK). At 50, 100, and 150% NPK, a positive balance of N at 8.7, 123.5, and 246.6 kg

Table 2. Mean nutrient uptake over 25 years (1971–95) at 100% NPK fertilization in rice-wheat system at Barrackpore, India.

Crop	N	P	K	Ca	Mg	Cu	Mn	Zn	Fe
	(kg ha^{-1})			(g ha^{-1})					
Jute	55.4	13.6	75.7	89.7	26.7	13	223	291	1843
Rice	76.3	13.1	78.5	22.2	17.3	26	620	275	1334
Wheat	50.3	8.0	61.1	19.0	15.1	14	132	233	1585

Table 3. Mean annual plant nutrient balance and change in soil test values between 1971 and 1995 in rice-wheat system at Barrackpore, India.

Treatment	Nutrient applied ($kg\ ha^{-1}$)			Nutrient uptake ($kg\ ha^{-1}$)			Nutrient balance ($kg\ ha^{-1}$)			Changes in soil test values[1] ($kg\ ha^{-1}$)		
	N	P	K	N	P	K	N	P	K	N	P	K
50% NPK	150	33	75	141.7	25.8	153.4	8.7	7.2	–78.4	34.6	19.8	43.3
100% NPK	300	66	150	176.5	32.2	211.4	123.5	33.7	–61.4	45.9	134.7	23.0
150% NPK	450	99	225	203.4	38.9	244.1	246.5	60.0	–19.1	59.4	153.7	35.5
100% NPK +$ZnSO_4$[2]	300	66	150	165.9	31.1	192.2	134.1	34.9	–42.2	37.3	43.3	55.3
100% NP	300	66	–	166.0	31.3	193.7	133.9	34.7	–193.7	15.9	51.0	34.1
100% N	300	–	–	156.4	29.4	183.8	143.6	29.4	–183.8	38.3	–22.4	32.9
100% NPK +FYM[3]	350	79	190	181.8	33.9	212.2	118.2	32.1	– 62.2	51.2	94.9	14.0
100% NPK (–S)	300	66	150	155.2	28.0	182.4	144.8	37.9	-32.4	35.9	50.1	59.6
Control	–	–	–	75.3	14.5	88.4	–75.3	–14.5	–88.4	33.4	–13.6	64.5

1. Changes in soil test values (STV)=STV after 25 years – initial STV.
2. @ 10 kg $ZnSO_4$ ha^{-1} in wheat.
3. @ 10 t farmyard manure (FYM) ha^{-1} in jute.

ha^{-1} respectively was recorded. The corresponding values for P were 7.2, 33.7, and 60.0 kg ha^{-1} respectively. After 25 years available N at 50, 100, and 150% NPK treatment was 34.6, 45.9, and 59.4 kg ha^{-1} respectively. The corresponding values for available P were 19.8, 134.7, and 153.7 kg ha^{-1} respectively. Interestingly at 50, 100, and 150% NPK, the available K status in soil showed an increasing trend ranging from 23.62 kg ha^{-1} to 43.28 kg ha^{-1} from the initial soil K status.

No significant change in soil reaction was observed when initial pH value was compared with that of soil sampled after 25 years of intensive cropping. Organic carbon content decreased from initial status in all the treatments (Fig. 8). The extent of decline was more in control plots (23.5%) and was comparatively lower in 100% NPK plus FYM (10.2%) treated plots. In a number of permanent plot rotational experiments conducted on different soil types, the organic carbon level of the plow layer got appreciably exhausted in spite of the regular incorporation of bulky organic manures, and cumulative effect of inorganic fertilizer was relatively small (Subba Rao 1979). In a continuous cropping sequence of wheat, jute, and rice 18% decline in organic carbon in control plot was observed by Mandal et al. (1984).

Nitrogenous fertilizer does not remain in soil for a long time but due to its continuous application over years, build-up in soil available N was observed in all treated plots in comparison to initial soil status (Fig. 9; Table 3); 150% NPK treatment recorded highest increase in available N after 25 years. An increase in available N from initial level was found with increasing doses of N either alone or in combination with P and K. Incorporation of FYM in conjunction with 100% NPK recorded appreciable increase in available N after 25

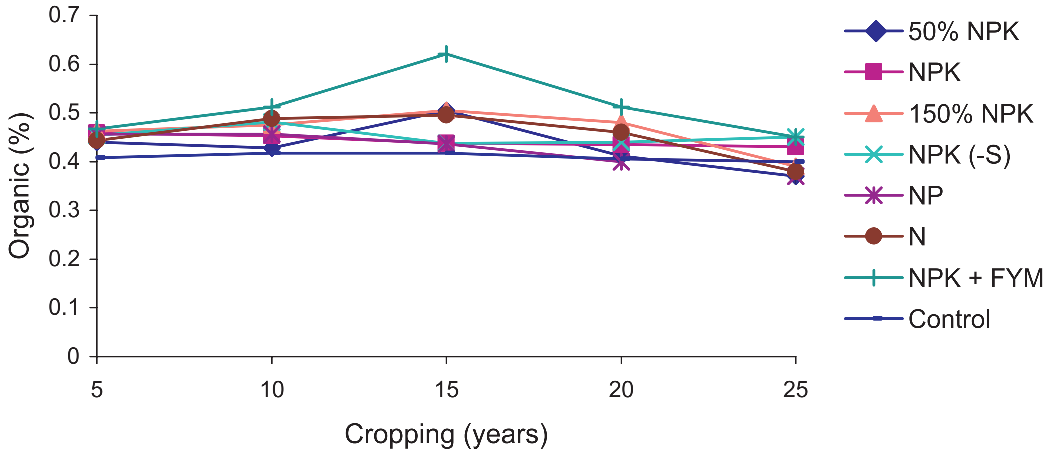

Figure 8. Organic carbon (OC) in soil under various fertilizer treatments in rice-wheat system during 1971–95 at Barrackpore, India.

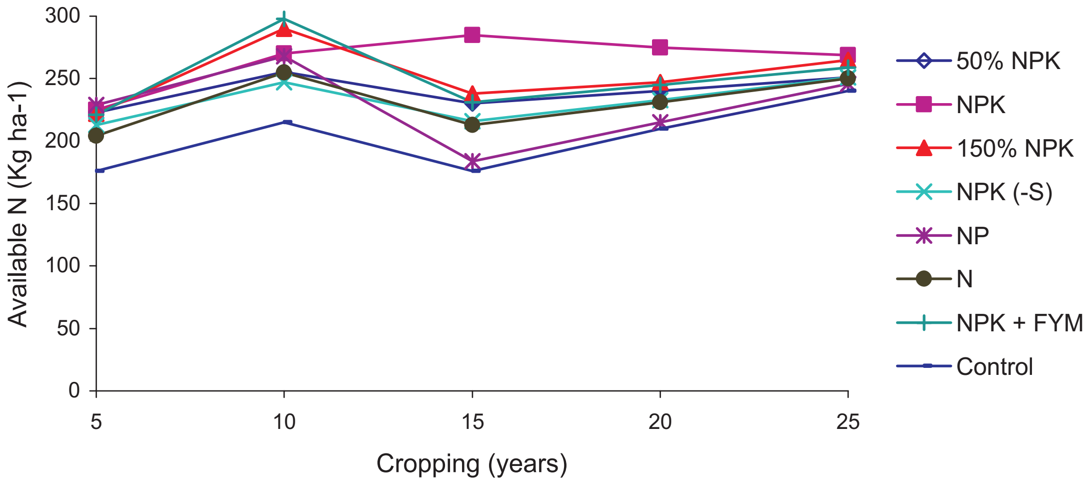

Figure 9. Soil available nitrogen (N) under various fertilizer treatments in rice-wheat system during 1971–95 at Barrackpore, India (initial value=214.54 kg N ha^{-1}).

years. Feigin et al. (1974) also observed significant increase in N availability of soil with FYM. However, increase in available N from initial status in control plot was very small. Interestingly build-up of available N at 100% N treatment was more than that of 100% NP treatment indicating higher crop removal of N in the latter.

Intensive cropping with high-yielding varieties over 25 years reduced the level of available P in control and 100% N-treated plots. The magnitude of decrease was more in the latter which might be due to higher removal of P by the crops. Available P content increased with increasing levels of NPK fertilizers (Fig. 10; Table 3).

Regular application of K fertilizer enhanced available K in spite of negative K balance after 25 years (Fig. 11; Table 3). Increase in available K was 23–43%. The increase in available K in spite of negative K balance might be attributed to release of substantial

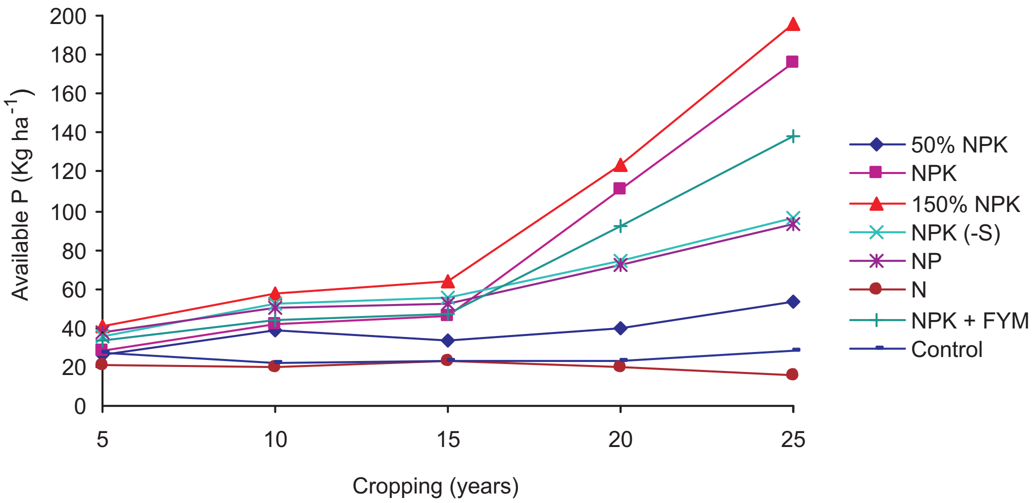

Figure 10. Soil availabe phosphorus (P) nder various treatments in rice-wheat system during 1971–95 at Barrackpore, India (initial value=49.49 kg P ha^{-1}).

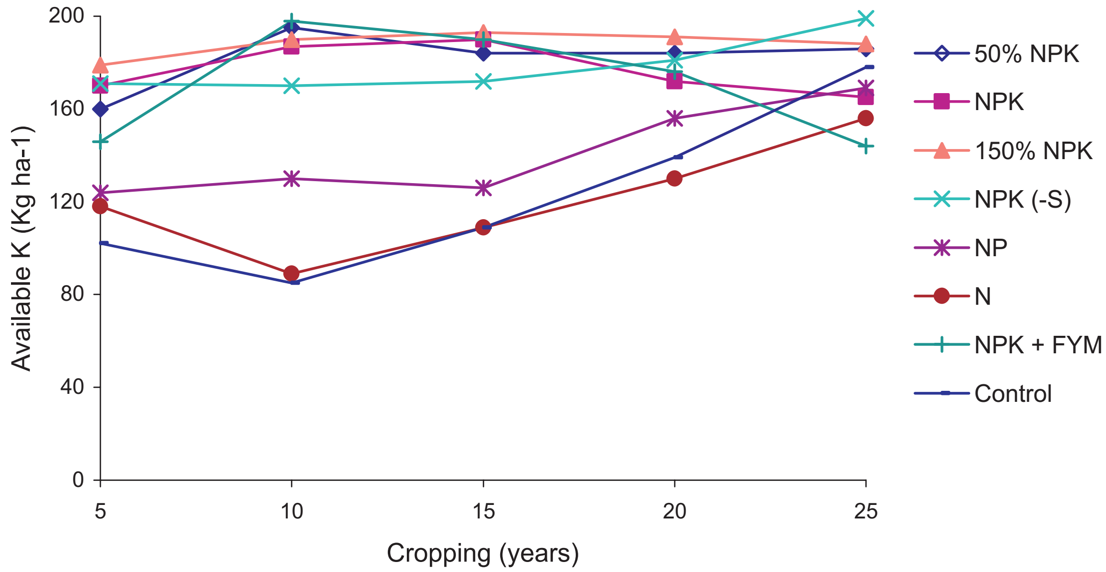

Figure 11. Soil available potassium (K) under various fertilizer treatments in rice-wheat system during 1971–95 at Barrackpore, India (initial value=135.03 kg K ha^{-1}).

amount of K from non-exchangeable sources. The decrease in soil K after first 15 years of cultivation was replenished after 25 years and build-up of soil K was observed even in plots where no potassic fertilizer was added. Prasad et al. (1982), however, did not find any appreciable decline in available K level when no fertilizer K was being applied. The available K contents in soil in 100% N, 100% NP, and 100% NPK + FYM treated plots were less as compared to the control plot and were 12, 5, and 9% respectively.

After 25 years of cropping, a general decline in available Zn content over the initial status was perceptible in all treatments including that where Zn was added as $ZnSO_4$ during wheat cropping (Fig. 12). After successive cropping over the years a rise in available Fe status was manifested in all treatments, including control plot (Fig. 13). Application of S-bearing fertilizers, viz., ammonium sulfate, single superphosphate, and zinc sulfate increased available S. The highest increase in available S (15.20 mg kg^{-1}) was noticed with 150% NPK. However, decreasing trend in available S was noticed in control and S-free treated plots (Fig. 14).

Conclusion

Build-up of nutrient status in soil through continuous application of manures and fertilizers over the years was not reflected in crop yield. Rather, a decreasing trend in yield was observed. To raise three crops a year, duration of the crops should be considered for crop management. If high-yielding, fertilizer-responsive, and short-duration varieties are

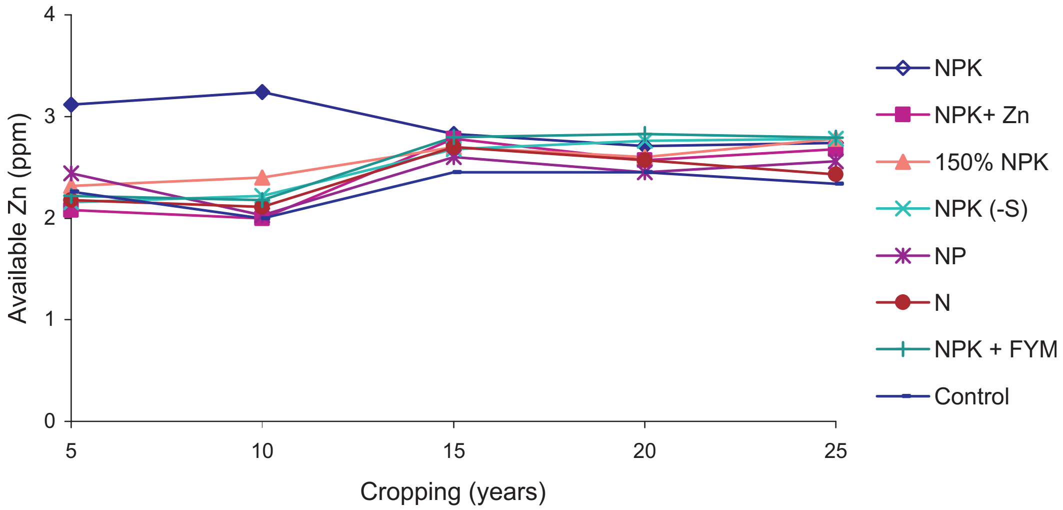

Figure 12. Soil available zinc (Zn) under various fertilizer treatments in rice-wheat system during 1971–95 at Barrackpore, India (initial value=2.87 ppm).

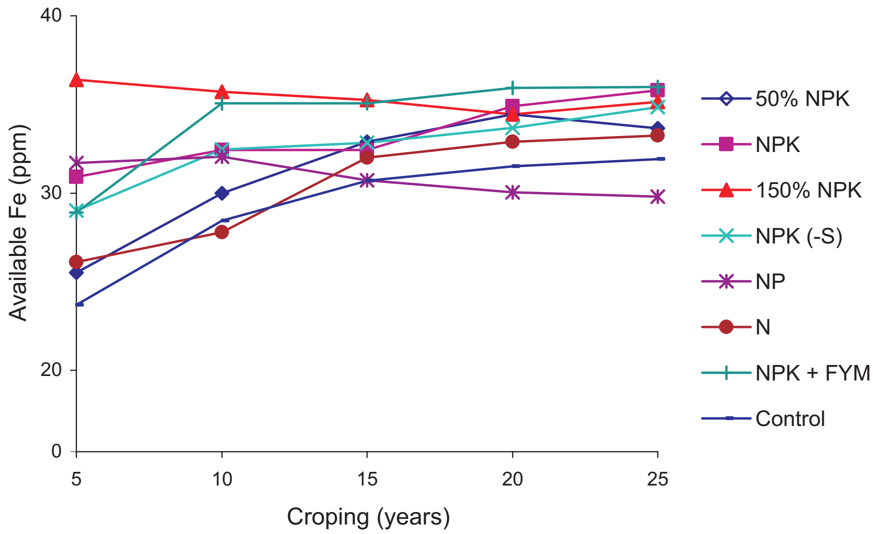

Figure 13. Soil available iron (Fe) under various treatments in rice-wheat system during 1971–95 at Barrackpore, India (initial value=29.10 ppm).

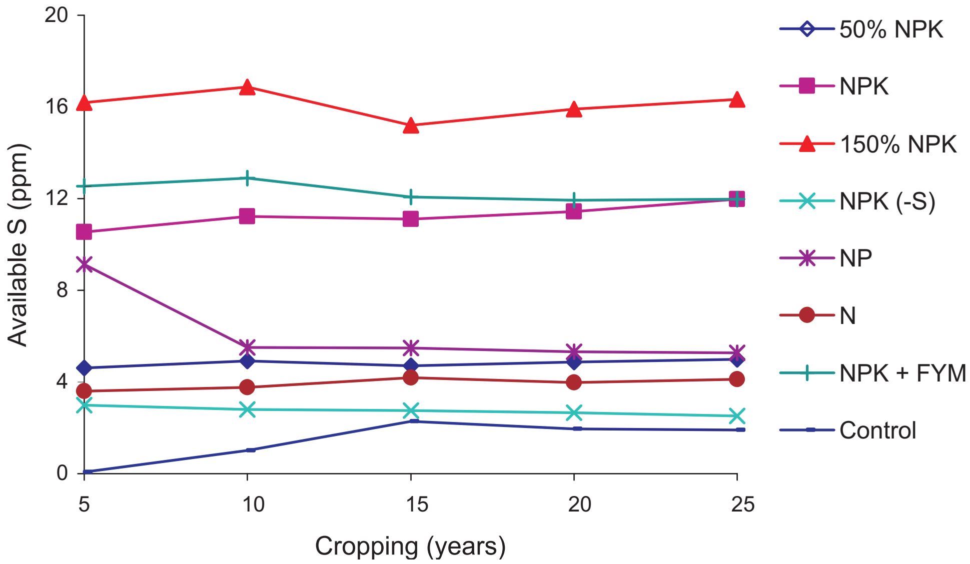

Figure 14. Soil available sulfur (S) under various fertilizer treatments in rice-wheat system during 1971–95 at Barrackpore, India (initial value=3 ppm).

available, the entire program can effectively be carried out to exploit the full potential of yield parameters. In future, biofertilizers may be accommodated in the experiment to find out the sustainability of bio-inputs considering the productivity and replenishment of nutrient status through dissolution of nutrients from soil reserve.

References

Feigin, A., Helevy, J., Kafkafi, U., and **Sagir, B.** 1974. Cumulative effects of manures applied with and without fertilizers on nutrient availability in the soil and on yield of crops under irrigation. Agril. Res. Org. Volcani Centre 32:30.

Jackson, M.L. 1967. Soil chemical analysis. New Delhi, India: Prentice Hall of India Pvt. Ltd. 498 pp.

Kanwar, J.S., and **Prihar, S.S.** 1962. Effect of continuous application of farmyard manure and inorganic fertilizers on crop yields and properties of soil. i. Chemical properties. Journal of the Indian Society of Soil Science 10:109–120.

Mandal, B.C., Roy, A.B, Saha, M.N., and **Mandal, A.K.** 1984. Wheat yields and soil nutrient status as influenced by continuous cropping and manuring in a jute-rice-wheat rotation. Journal of the Indian Society of Soil Science 32:696–700.

Prasad, B., Singh, R.P., Roy, H.K., and **Sinha, H.** 1983. Effect of fertilizer, lime and manure on some physical and chemical properties of a red loam soil under multiple cropping. Journal of the Indian Society of Soil Science 31:601–603.

Prasad, B., Sinha, K., and **Sinha, N.P.** 1982. Effect of continuous application of manure and fertilizers on available soil potassium and its uptake by potato. Journal of the Indian Society of Soil Science 30:235–236.

Subba Rao, A. 1979. Effect of intensive cropping and fertilizer use on crop yield, nutrient uptake and changes in soil chemical properties. Ph.D. thesis, PG School, Indian Agricultural Research Institute, New Delhi, India.