Long-term Effects of Nitrogen, Phosphorous, Potassium, and Zinc Management on Crop Yields and Micronutrients Availability in Rice-Wheat Cropping System on Calcareous Soils

R Sakal[1]

Abstract

A long-term experiment was conducted to evaluate the effects of N, P, K, and Zn management on crop yields and micronutrients availability in rice-wheat cropping system on calcareous soils at Pusa (Bihar). The rising levels of NPK (0, 50, 100, and 150% of recommended dose) progressively increased the crop yields and uptake of micronutrients (Zn, Cu, Fe, and Mn) in rice-wheat-sorghum (forage) system as noted up to 10 cropping cycles. Magnitude of yield response to NPK application was higher in wheat followed by sorghum and rice. The yield showed decreasing trend at all doses of NPK with the increase of cropping cycle period and resulted in higher magnitude of decrease in control (no NPK) treatment. Among the crops, maximum reduction in yield was noted in rice, followed by wheat and sorghum. Zinc emerged as most limiting micronutrient in this cropping sequence. No S deficiency was detected due to application of single superphosphate as source of P which inadvertently supplied S to the crops due to presence of 12% S in it. In another study of rice-wheat system up to 8 cropping cycles, application of Zn at 10 kg ha^{-1} to first rice crop and Zn @ 10 kg ha^{-1} at 3-crops interval showed the highest yield response in this system and raised soil available Zn to adequacy level. DTPA-extractable Zn in postharvest soil showed decreasing trend with the advancement of cropping cycle period, especially in those treatments which received Zn application once with first crop only. Application of Zn at 5 kg ha^{-1} to each crop did not prove profitable but increased Zn content in the soil.

Introduction

In India, rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) are the two most important cereals that provide basic food. Cultivation of two cereals in a year, continuously year after year has led to decrease in soil fertility and a general decline of crop yields in response to applied nutrients. In several long-term fertilizer experiments, attempts were made to monitor the yield levels and sustainability of rice-wheat cropping system at varying levels of fertilizers. Nambiar and Abrol (1989) analyzed long-term manurial experiments conducted in India and evinced the declining trend in productivity despite balanced use of NPK (nitrogen, phosphorus, potassium) fertilizers. The decrease in productivity was observed to be associated with the new emerging problems of deficiency of micronutrients such as zinc (Zn) and of secondary nutrients such as sulfur (S).

Meager information is available on long-term effect of varying soil fertility levels on yield trend, uptake of micronutrients by crops, and the depletion or build-up of micronutrients in calcareous soils of Bihar under rice-wheat

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1. Rajendra Agricultural University, Pusa, Samastipur 848 125, Bihar, India.

Sakal, R. 2000. Long-term Effects of Nitrogen, Phosphorous, Potassium, and Zinc Management on Crop Yields and Micronutrients Availability in Rice-wheat Cropping System on Calcareous Soils. Page 73–82 *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.

system. Hence an attempt was made to conduct research on these aspects under rice-wheat-sorghum forage system and also on the dose and frequency of Zn application in rice-wheat system for sustaining productivity.

Materials and Methods

The experimental site selected at Pusa Farm was previously managed by the university growing rice or maize (*Zea mays* L.) in rainy season, wheat in winter, and sorghum (*Sorghum bicolor* (L.) Moench.) (forage) or mung bean (*Vigna radiata* L. Wilczek) in summer with nominal dose of fertilizers giving more emphasis to nitrogenous fertilizers. The source of irrigation is tube well having good quality of water. The present experiment was initiated at the aforesaid site (Pusa Experimental Farm) falling under hot sub-humid agroecological zone. To study the effect of varying fertility levels on crop yields and the removal of micronutrients, a long-term field experiment under rice-wheat-sorghum cropping sequence was started in monsoon 1985 and continued for 10 cropping cycles. The experiment was laid out in micro-plots (4 m × 2.5 m) maintaining 4 levels of N, P, and K, viz., F0 = No NPK, F1 = 50% of recommended dose of NPK, F2 = 100% of recommended dose of NPK, and F3 = 150% of recommended dose of NPK. These 4 treatments were replicated 6 times in a randomized block design. Recommended doses of $N:P_2O_5:K_2O$ for rice or wheat and sorghum were 100:50:50 kg ha^{-1} and 60:50:30 kg ha^{-1}, respectively. Rice, wheat, and sorghum varieties tested were Jaya, HP 1102, and Pusa local, respectively. Nitrogen was applied as urea, P as single superphosphate, and K as muriate of potash. Urea was applied in 3 splits: half dose just before sowing followed by mixing with plow layer soil, one-fourth at tillering and one-fourth at panicle initiation as top-dressing in rice and wheat. In sorghum, half dose of urea was applied in soil just before sowing followed by mixing with plow layer soil and remaining half as side-dressing at knee high stage. Entire dose of single superphosphate and muriate of potash was applied in soil just before sowing followed by mixing with plow layer in all the crops. Rice and wheat were grown till maturity, whereas sorghum was harvested at pre-flowering stage for forage. Grain and straw yields of rice, wheat, and dry forage yield of sorghum were recorded. Rice and wheat straw was not returned to soil as residue but it was used for cattle feed. Plant samples taken at harvest of each crop were washed in acidified detergent solution, rinsed with deionized water, dried in hot air oven at 65°C, pulverized in a Waring blender and digested in a mixture of 10:4:1 of $HNO_3:HClO_4:H_2SO_4$ (Jackson 1973). Total zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) in clear aliquot were determined by an atomic absorption spectrophotometer (Model GBC-902). Postharvest soil samples collected after every 2 cycles of rotation at 0–15 cm depth from 3 points in each plot were composited and examined for DTPA-extractable Zn, Cu, Fe, and Mn by atomic absorption spectrophotometry (Lindsay and Norvell 1978). The pH, electrical conductivity, organic carbon, and free $CaCO_3$ in the initial soil sample were 8.8, 0.54 dS m^{-1}, 0.45%, and 37.5%, respectively.

An experiment on dose and frequency of Zn application in rice-wheat cropping system was conducted in monsoon 1987 at the Pusa Experimental Farm near above-mentioned experimental plot. There were 10 treatments replicated 4 times in randomized block design. The plot size was 5 m × 2 m. Rice cv Sita was grown in monsoon, followed by HP 1102 (wheat) in winter. The fertilizer levels applied to both crops were 110 kg N ha^{-1} as urea, 60 kg P_2O_5 as single superphosphate, and 50 kg K_2O as muriate of potash, respectively. The method of fertilizer application, plants sampling, and their preparation for Zn analysis and postharvest soil sample collection from 0–15 cm depth after each cropping cycle for DTPA-extractable Zn analysis was similar as described in the rice-wheat-sorghum cropping sequence. This experiment was continued till 8 cropping cycles. Rice and wheat straw was used as cattle feed. The initial soil had pH 8.8, electrical conductivity 0.36 dS m^{-1}, organic carbon 0.32%, free $CaCO_3$ 34.7%, and DTPA-extractable Zn 0.56 mg kg^{-1}. In both the experiments, the yield of unhusked rice grain was recorded.

The effect of graded doses of NPK fertilizers at 0% (F0), 50% (F1), 100% (F2), and 150% (F3) of the recommended dose to respective crops was evaluated on crop yields and yield trends, micronutrient uptake by crops, and available micronutrient status in postharvest soil in a long-term field experiment under rice-wheat-sorghum sequence up to 10 cropping cycles. Influence of dose and frequency of Zn application in rice-wheat system for crop yields, Zn uptake by crops, and DTPA-extractable Zn in postharvest soil up to 8 cropping cycles was also studied.

Results and Discussion

Crop yields and trends

Increasing doses of NPK progressively increased the yield of each crop with varying magnitude, and continuous cropping without NPK application resulted in lowest yield. During the initial 3 years (1985–88) there was an increase in yield of 63, 91, and 132% in rice grain, 84, 135, and 176% in wheat grain, and 46, 105, and 161% in sorghum in F1, F2, and F3 treatments respectively. The results indicate that wheat is more responsive to NPK than rice. The results confirm the findings of Singh et al. (1989) in rice-wheat system up to 5 cropping cycles where rising doses of NPK progressively increased the crop yields with higher quantum of yield response in wheat compared to rice in calcareous soils. Nand Ram (1995) in a long-term field experiment on Mollisol at Pantnagar also reported more response of wheat to NPK than rice. Trend in yield of rice, wheat, and sorghum during 1985–95 with rolling average for 3 annual cropping cycles is depicted in Figures 1, 2, and 3. The yield showed a declining trend. The average yield in F0, F1, F2, and F3 treatments decreased from 2.14, 3.48, 4.08, and 4.96 t ha^{-1} for rice grain; 1.51, 2.78, 3.55, and 4.17 t ha^{-1}

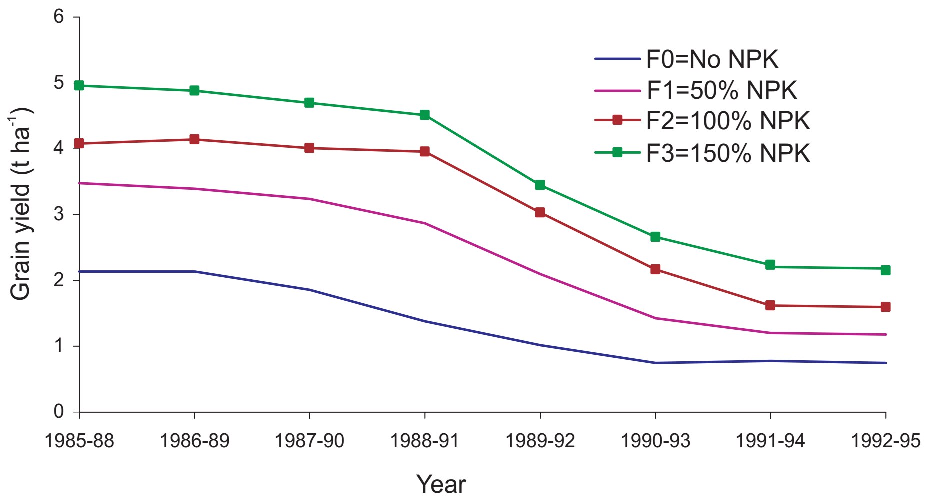

Figure 1. Long-term effect of graded doses of NPK fertilizers on grain yield of rice (3 years rolling average) in rice-wheat system at Pusa, India.

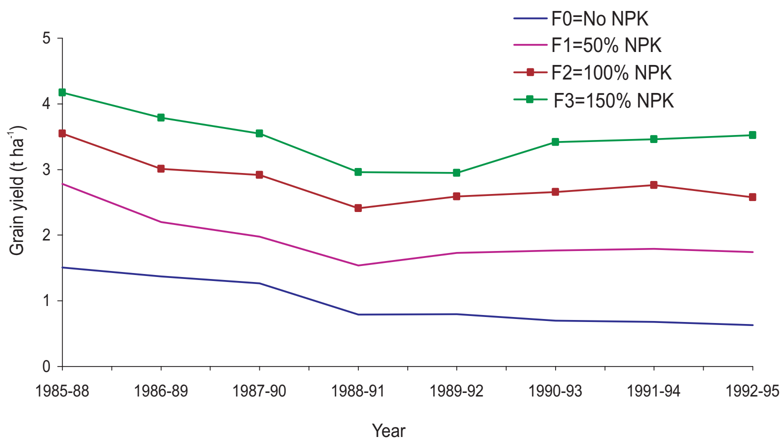

Figure 2. Long-term effect of graded doses of fertilizers on grain yield of wheat (3 years rolling average) in rice-wheat system at Pusa, India.

for wheat grain; and 3.14, 4.60, 6.43, and 8.18 t ha^{-1} for sorghum during the first 3 years (1985–88) to 0.75, 1.18, 1.60, and 2.15 t ha^{-1} in rice; 0.63, 1.74, 2.58, and 3.52 t ha^{-1} in wheat; and 1.55, 3.77, 5.44, and 6.91 t ha^{-1} in sorghum during the last 3 years (1992–95), respectively. Hence, decrease in yield in F0, F1, F2, and F3 treatments was 65, 66, 61, and 57% in rice; 58, 37, 27, and 16% in wheat; and 51, 18, 15, and 16% in sorghum respectively. Maximum reduction in yield was recorded in rice, followed by wheat and sorghum. Within different NPK doses of individual crop, more reduction in yield was noted in the treatment receiving no NPK (F0) where crops are dependent only on inherent soil fertility, which is continuously depleting. Increasing doses of NPK tended to resist the reduction in yield owing to continuous supply of basic nutrient elements such as NPK to plants. Greater reduction in rice yield than wheat and sorghum may be ascribed to large changes in soil environment during rice cultivation. Rice crop was grown during monsoon period having too much fluctuations in weather conditions such as frequent cloudiness and sometimes heavy rain at or just after transplanting leading to submergence, drought during flowering period, Zn deficiency, and more pests and diseases which may decrease the rice yield.

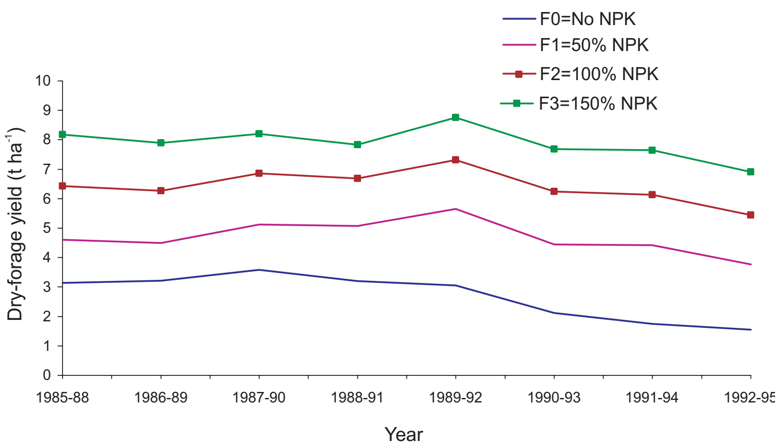

Figure 3. Long-term effect of graded doses of NPK fertilizers on dry sorghum forage yield (3 years rolling average) in rice-wheat system at Pusa, India.

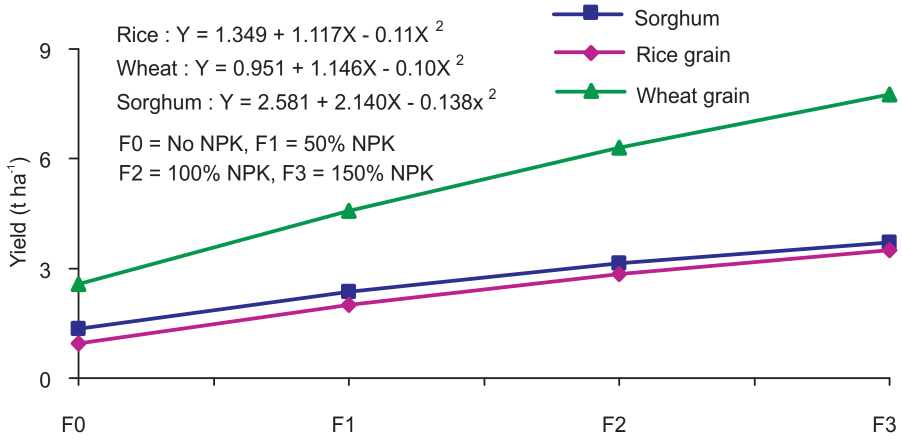

Figure 4. Response of crops to graded doses of NPK fertilizers (based on 10 years average) in rice-wheat system at Pusa, India (F0=No NPK; F1=50% NPK; F2=100% NPK; F3=150% NPK).

Table 1. Effect of NPK levels on micronutrients uptake by rice, wheat, and sorghum crops up to 10 cropping cycles at Pusa, Bihar, India.

Fertilizer level[1]	Rice	Wheat	Sorghum	Total
Zn uptake (kg ha^{-1})				
F0	1.00	0.72	0.79	2.53
F1	1.72	1.44	1.39	4.55
F2	2.31	1.93	1.82	6.06
F3	2.42	2.18	1.93	6.53
Mean	1.86	1.57	1.48	4.92
Cu uptake (kg ha^{-1})				
F0	0.42	0.31	0.35	1.08
F1	0.72	0.66	0.66	2.04
F2	1.01	0.94	0.87	2.82
F3	1.14	1.05	0.94	3.13
Mean	0.82	0.74	0.71	2.27
Fe uptake (kg ha^{-1})				
F0	8.3	5.2	6.8	20.3
F1	13.3	10.0	10.6	33.9
F2	18.3	13.9	14.6	46.8
F3	20.8	17.4	15.5	53.7
Mean	15.2	11.6	11.9	38.7
Mn uptake (kg ha^{-1})				
F0	3.2	0.5	0.8	4.5
F1	6.5	1.0	1.5	9.0
F2	9.0	1.5	1.9	12.4
F3	10.5	1.8	3.2	15.5
Mean	7.3	1.2	1.9	10.4

1. Level of N-P_2O_5-K_2O; F0=0-0-0; F1=50-25-25; F2=100-50-50; F3=150-75-75% of recommended NPK level.

Table 2. Effect of varying NPK levels on available micronutrients in postharvest soil after 10 cropping cycles in rice-wheat-sorghum system at Pusa, Bihar, India.

Fertilizer level[1]	Available micronutrients in postharvest soil (mg kg^{-1})			
	Zn	Cu	Fe	Mn
F0	0.89	2.45	14.06	4.15
F1	0.74	2.37	18.71	4.28
F2	0.63	2.33	20.01	5.59
F3	0.52	2.32	19.13	5.50
CD (P = 0.05)	0.07	NS	1.16	0.47
Initial value	3.26	1.82	12.60	7.80

1. Level of N-P_2O_5-K_2O; F0=0-0-0; F=50-25-25; F2=100-50-50; F3=150-75-75% of recommended NPK level.

The response curves developed for rice, wheat, and sorghum at different NPK doses based on 10 years average yield data are depicted in Figure 4. The curves have not flattened or become asymptotic even at highest dose of NPK (F3). These curves show that yield is increasing in decreasing order with rising NPK doses, as evident from the regression equation of each curve following the second-degree polynomial function or quadratic nature showing negative value of 'C'. The curves would have been asymptotic and thereafter declined if the doses of NPK were higher than that used in the present investigation.

Micronutrient uptake by crops

Increasing doses of NPK progressively increased the Zn uptake by rice, wheat, and sorghum (Table 1). On the basis of mean uptake value, rice removed more Zn, followed by wheat and sorghum. Hence Zn management in rice crop is an important issue. Total removal of Zn by these 3 crops was 2.53–6.53 (average 4.92) kg ha^{-1}. Copper uptake showed an increase with the increase in NPK dose. Mean Cu removal by rice, wheat, and sorghum fodder was 0.82, 0.74, and 0.71 kg ha^{-1}, respectively (Table 1). Rice removed more Cu than wheat and sorghum. Total Cu removal by all the 3 crops ranged between 1.08 and 3.13 (average 2.27) kg ha^{-1}. Iron and Mn removal by rice crop was more than wheat and sorghum as these elements in rice soil are present in readily available form. In rice and sorghum the uptake pattern was Fe > Mn > Zn > Cu and in wheat it was Fe > Zn > Mn > Cu.

DTPA-extractable micronutrients

The DTPA-extractable Zn in soil decreased from 0.89 mg kg^{-1} to 0.52 mg kg^{-1} with increasing NPK dose, and there was remarkable decrease from its initial value of 3.26 mg kg^{-1} (Table 2). No change in soil available Cu was noted. Available Mn showed rising trend with increasing NPK doses in comparison to control (F0). However, available Mn in the initial soil sample was 7.80 mg kg^{-1} which is higher than 5.50 mg kg^{-1} recorded in F3 treatment. This shows an overall depletion in Mn content due to continuous cropping. Soil available Fe showed an increasing trend due to cropping compared with its initial value of 12.6 mg kg^{-1} (Table 2). Singh et al. (1989) in a field experiment on rice-wheat sequence in calcareous soil after 5 cropping cycles observed a declining trend in available Zn, Cu, and Mn of postharvest soil with increasing NPK doses, whereas at 150% NPK dose, soil available Zn, Cu, and Mn decreased from the

Table 3. Effect of rate and frequency of Zn application on DTPA-extractable Zn (mg kg^{-1}) in soil after each cropping cycle under rice-wheat cropping sequence at Pusa, Bihar, India.

Treatment	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95
T1= No Zn	0.49	0.39	0.33	0.31	0.27	0.24	0.22	0.20
T2 = 5 kg Zn ha^{-1} to 1st crop only	1.40	0.87	0.50	0.48	0.40	0.29	0.25	0.23
T3 = 5 kg Zn ha^{-1} to each crop	3.16	4.22	3.64	4.12	3.95	4.45	3.57	3.90
T4 = 5 kg Zn ha^{-1} to alternate crop	1.30	1.87	1.89	3.19	2.70	2.40	2.48	2.52
T5 = 10 kg Zn ha^{-1} to 1st crop only	3.21	1.72	1.32	0.88	0.78	0.57	0.54	0.47
T6 = T5 + 5 kg Zn ha^{-1} to alternate crop	3.06	3.14	2.88	3.02	2.93	2.38	2.48	2.84
T7 = T5 + 5 kg ha^{-1} at 2-crops interval	3.05	2.28	1.69	2.58	3.42	2.03	1.98	1.82
T8 = T5 + 10 kg ha^{-1} at 3-crops interval	3.04	1.80	2.82	1.78	2.50	2.26	2.45	1.77
T9 = 15 kg Zn ha^{-1} to 1st crop only	3.99	1.93	1.41	0.98	0.78	0.60	0.58	0.43
T10 = 20 kg Zn ha^{-1} to 1st crop only	5.07	2.45	1.88	1.15	0.94	0.85	0.71	0.56
CD (P = 0.05)	0.34	0.20	0.47	0.21	0.34	0.26	0.16	0.18

initial value of 2.93 to 1.25, 2.21 to 1.85, and 6.30 to 4.31 mg kg^{-1}, respectively. Soil available Fe increased from its initial value 10.5 mg kg^{-1} to 16.6 mg kg^{-1} at 150% NPK dose. The build-up of Fe in soil was due to transformation of fixed form of Fe into available form by decomposed roots left over in the soil by each crop. Prasad et al. (1979) reported similar trend in Fe build-up in a long-term experiment. Nand Ram (1995) evaluated available micronutrients in postharvest soil after 20 years of cropping in rice-wheat cowpea (*Vigna unguiculata* (L.) Walp.) system on Mollisol, and reported that DTPA-extractable Zn decreased to 0.80 mg kg^{-1} at 100% NPK from the initial level of 2.7 mg kg^{-1}. Maximum depletion occurred at 150% NPK (0.63 mg kg^{-1}). Increasing trend in available Fe, Mn, and Cu was recorded compared to their initial values. At 150% NPK doses, the content of DTPA-extractable Fe, Mn, and Cu was 41, 28, and 4.4 mg kg^{-1} as against their initial values of 29.5, 26.8, and 2.9 mg kg^{-1}, respectively.

The results clearly showed an increase in DTPA-extractable Fe in postharvest soil of long-term experiments over the initial level. But no adequate reasoning on such issues has been given. Hence, there is a need to fractionate the soils of long-term experiments for different pools of Fe and other micronutrients. This may provide an explanation. The contribution of rice roots in supplying Fe to soil after their decomposition cannot be overlooked because rice roots contain large amount of Fe as compared to wheat roots. Iron coating on the surface of roots of rice was observed.

Crop response to Zn

The direct, residual, and cumulative effects of different Zn doses in rice-wheat system were evaluated in calcareous soil up to 8 cropping cycles at Pusa Farm by Sakal et al. (1994–95). Data for the 10 treatments (T1 to T10) are given in Table 3. The soil application of 10 kg Zn ha^{-1} as zinc sulfate to first crop of rice at transplanting and 10 kg Zn ha^{-1} at 3-crops interval (T8) was the appropriate dose and frequency of Zn application with average grain yield response of 1.47 t ha^{-1} yr^{-1} in rice and 0.74 t ha^{-1} yr^{-1} in wheat against the average grain yield in the control (no Zn) treatment of 1.95 and 2.37 t $ha^{-1}yr^{-1}$, respectively (Fig. 5). The cumulative Zn-uptake response for the cropping system up to 16 crops at T8 was 817 g ha^{-1}. Treatments T6 and T7 were found equally

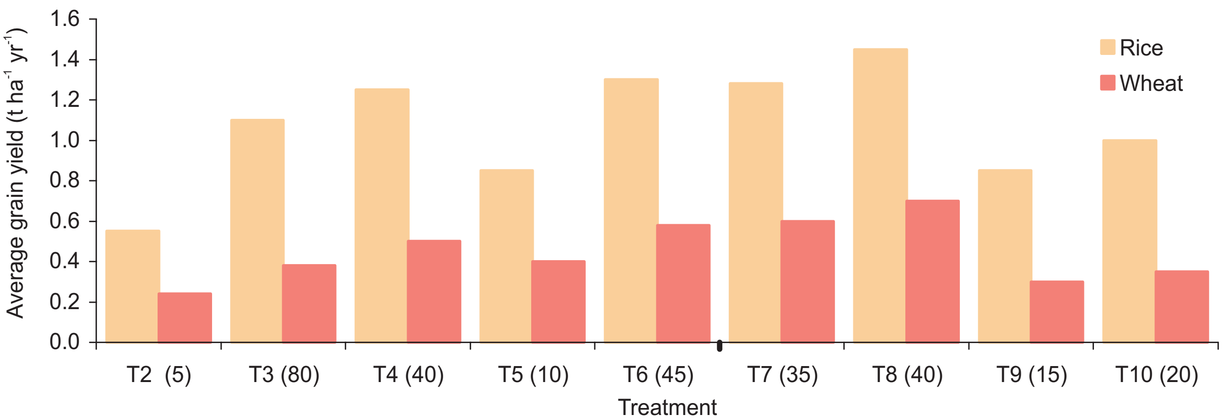

Figure 5. Effect of dose and frequency of zinc (Zn) application on average grain yield response of rice and wheat up to 8 cropping cycles at Pusa, India [see Table 3 for treatments; figures in parentheses on X axis indicate the total amount of Zn (kg ha^{-1}) added up to 8 cropping cycles; average grain yields per year in T1 (no Zn) were 1.95 t rice ha^{-1} and 2.37 t wheat ha^{-1}].

effective for grain yield response in both the crops with corresponding grain yield response of 1.35 and 1.34 t $ha^{-1}yr^{-1}$ in rice as well as 0.58 and 0.50 t ha^{-1} yr^{-1} in wheat. But T7 is considered superior to T6 because total amount of Zn added up to 8 cropping cycles is 35 kg ha^{-1} in T7 and 45 kg ha^{-1} in T6 for similar quantum of response (Fig. 5). Nayyar et al. (1990) in field experiment on Fatehpur sandy loam alkaline soil in Punjab and Rathore et al. (1995) in medium black clay soils at Jabalpur (Madhya Pradesh) observed that application of 5.5 kg Zn ha^{-1} to every alternate crop in rice-wheat system was the proper dose and frequency of Zn application for obtaining maximum yield response.

The available Zn in post-harvest soil at the cropping cycle 8 in T8 and T7 treatments was 1.77 and 1.82 mg kg^{-1}, respectively being quite above the threshold value of 0.78 mg kg^{-1} worked out for such soil (Sakal et al. 1982). The data on the effect of dose and frequency of Zn application on DTPA-extractable Zn after each cropping cycle is shown in Table 3. The DTPA-extractable Zn in soil progressively decreased with the advancement of cropping cycle period which is quite apparent in all those treatments where Zn was applied with first crop only (T2, T5, T9, and T10). The persistence of residual value of available Zn in these treatments depended on the quantity of Zn applied to first crop. The residual value of Zn in treatment T2, T5, T9, and T10 persisted up to 2, 4, 5, and 6 cropping cycles as soil available Zn approached threshold value of 0.78 mg kg^{-1} (Sakal et al. 1982). Addition of 5 kg Zn ha^{-1} to each crop was not found remunerative due to build-up of excess Zn in soil which might have caused an imbalance of nutrients in soil-plant system leading to lower magnitude of yield response. No Zn toxicity was noted on crops under this treatment (T3) in such highly calcareous soil. Hence phyto-toxicity may not be the cause of low yield response in T3 treatment.

Conclusion

In rice-wheat-sorghum cropping sequence, it was observed that increasing dose of NPK (0, 50, 100, and 150% of recommended dose) progressively increased the yields of all crops. No asymptotic behavior in response curve was noted even at 150% NPK dose. However, response curve has followed quadratic function showing yield increase in slightly decreasing order at higher NPK dose. It was further observed that wheat was more responsive to NPK followed by sorghum and rice in sequence. With the advancement of cropping cycle period, the yield tended to decrease at all doses of NPK. However, magnitude of decrease was higher in control (no NPK) treatment. While comparing the crops, maximum reduction in yield was noted in rice followed by wheat and sorghum. Zinc was the most limiting micronutrient in this cropping sequence.

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