Long-term Effects of Nitrogen, Phosphorus, and Potassium Fertilizers on Rice-Wheat Productivity and Properties of Mollisols in Himalayan Foothills

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Abstract

In rice-wheat sequential cropping, a long-term experiment, having varying levels of NPK (nitrogen, phosphorus, potassium) fertilizers, has been in progress since 1977 to assess response of these two crops to applied NPK fertilizers and to monitor sustainability of the system to crop productivity and soil fertility. Of the three nutrients, N is the key element affecting productivity of the system. Response of rice to applied N (maximum 120 kg ha^{-1}) was curvilinear in first five years, and linear later on. Response of wheat to N remained curvilinear throughout. Economic efficiency of N applied to rice was high at low N-level in the first five years, but it was on par at all N levels during the subsequent years. For wheat, agronomic efficiency is always higher at low N levels. Nature of response and agronomic efficiency show that 120 kg N ha^{-1} is no more adequate, particularly for rice, and high N-levels need to be tested. The rice-wheat system in terms of its productivity is no more sustainable at low N levels. The response to P has been observed during the past 3 years only when available soil P level had reached 13 mg kg^{-1} soil. Phosphorus application raised rice and wheat productivity by 10%. There was no response to K application. Nutrient balance studies show negative balance of N up to the highest N level, and this has resulted in decline in soil-N status. The balance of K is also negative but it did not make much difference in soil exchangeable-K. The balance of P is negative at low levels, but at high P level (80 kg P_2O_5 ha^{-1}) it has been positive which has resulted in build-up of soil P. The yield trends over the years show that with low N rates (0 and 40 kg ha^{-1}) there has been significant decline in rice yield, but at levels of 80 and 120 kg ha^{-1} rice yield was maintained. The plots receiving no fertilizer for last 18 years yield about 2 t of rice ha^{-1} and 1.5 t of wheat ha^{-1}.

Introduction

In northwest India, areas in Himalayan foothills were under forest cover nearly five decades ago. These areas have been brought into agricultural production because of high native soil fertility and favorable water availability and have been intensively cropped for the past three decades. Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) double cropping is the predominant crop sequence. This practice of continuous cereal cultivation, which was considered bad farming in the last century, is now common. Intensive cultivation of this relatively young fertile soil and use of chemical fertilizer led to the establishment of a long-term experiment at Pantnagar, India in 1977 to investigate sustainability of rice-wheat system and nutrient dynamics in the long-term. The experiment had graded levels of NPK (nitrogen, phosphorus, potassium) fertilizers to determine appropriate fertility management

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strategies for this soil, and understanding how these should be refined with long-term cropping. It would also indicate changes in input-response pattern and any nutrient deficiencies, which may develop, over time.

Materials and Methods

Site characteristics

Pantnagar is located at 29° N, 79.3° E, and at an altitude of 243.8 m above sea level. The climate is humid subtropical with mean annual minimum temperature of 16.6°C and maximum temperature of 30.5°C. The region receives mean annual rainfall of 1,430 mm. The soil of the experimental field belongs to Mollisol order and has 28% sand, 42% silt, and 30% clay (sandy loam).

Experimental design and measurements

The experiment has 3 levels of N (40, 80, 120 kg ha^{-1}) and 3 levels of P_2O_5 (0, 40, 80 kg ha^{-1}). A total of 18 combinations of NPK are arranged in a factorial partially confounded design with one control plot (no fertilizer) in each of the 3 blocks of each replication. Thus there are 21 plots in each of the 4 replications. The plot size is 6.4 × 5 m. The same treatments are applied to each crop.

Transplanted rice was raised regularly during summer (June/July–October) and wheat during winter (November–April). Even before this experiment, the field was under rice-wheat rotation. Rice variety Jaya was tested up to 1984 and then it was replaced by Pant Dhan 4. Sonalika wheat, was grown up to 1985 and then it was replaced by UP 2003. The change in crop varieties was necessary due to the development of disease susceptibility in initial varieties. A dose of 50% N (as urea) was applied as a basal dose and 50% was top-dressed 30 days after transplanting in rice and 1 day before the second irrigation of the wheat crop. The entire P (single superphosphate) and K (muriate of potash) was applied as a basal dose. Both rice and wheat crops were irrigated, but due to high infiltration rate, even after puddling, standing water was generally not maintained in rice.

The yield of grain and straw was measured every season. In some years, biometric observations on plant growth and yield attributes were also made. Nutrient (NPK) uptake was measured in certain years and data were used to estimate nutrient balance. Periodically soil samples were collected from the top layer of 0–20 cm from each plot and were analyzed.

Results and Discussion

Crop response to nutrient inputs

Nitrogen. The experiment was initiated in 1977/78 and data were analyzed up to 1994/95. During these 18 years, yield of crops in 3 years was unusually low due to external factors, which are not used in the analysis. Data for remaining 15 years have been grouped in 3 periods of 5 years each (P1, P2, P3). During the first 5 years (P1), response of rice to N averaged over P and K levels was curvilinear with significant response up to 80 kg N ha^{-1} only (Fig. 1). During next 10 years (P2 and P3), response to N was linear indicating that optimum lies beyond the highest N level of 120 kg ha^{-1} included in the experiment. The agronomic efficiency of rice (kg grain produced kg^{-1} N applied) at 40 kg N level was highest and it declined with increasing N rates (Fig. 2), but in later years, particularly during P3, agronomic efficiency was more or less on par at all the N levels. This shows that the N suplying capacity of soil to rice declined over years and, therefore, in later the years crop responded up to the highest N level. This is further confirmed by decline in rice yield in control plots over years (Fig. 1). In 1977, mean

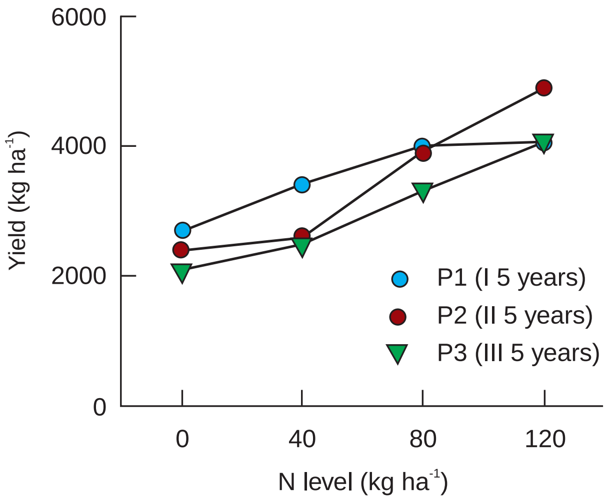

Figure 1. Response of rice to nitrogen (N) at different periods (P1, P2, P3) of cropping in rice-wheat system at Pantnagar, India.

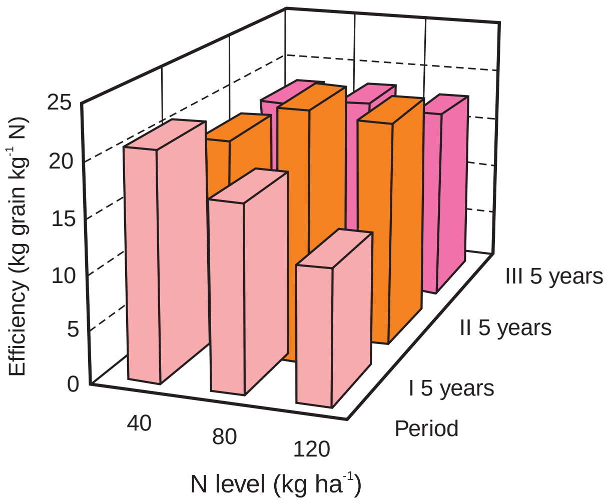

Figure 2. Agronomic efficiency of wheat at different nitrogen (N) levels at different periods of cropping in rice-wheat system at Pantnagar, India.

rice yield without any fertilizer was 2.8 t ha^{-1} which declined to 2.2 t ha^{-1}. The Terai soils were initially very fertile, but continuous intensive cropping has reduced the fertility.

Wheat yield in control plots (without any fertilizer) was low (1,400 kg ha^{-1}), but the response of wheat to N was much higher compared to rice (Fig. 3). With 40 kg N ha^{-1}, wheat yield increased by 1300–1400 kg ha^{-1}. At higher levels of N, response of wheat was also much higher compared to rice. In P1 and P2, 80 kg N ha^{-1} was sufficient to achieve highest wheat yield, without any significant increase by higher (120 kg N ha^{-1}) N level, but in later years response to 120 kg N ha^{-1} was significant. The agronomic efficiency of wheat was much higher than that of rice (Fig. 4). At 40 kg N level, each

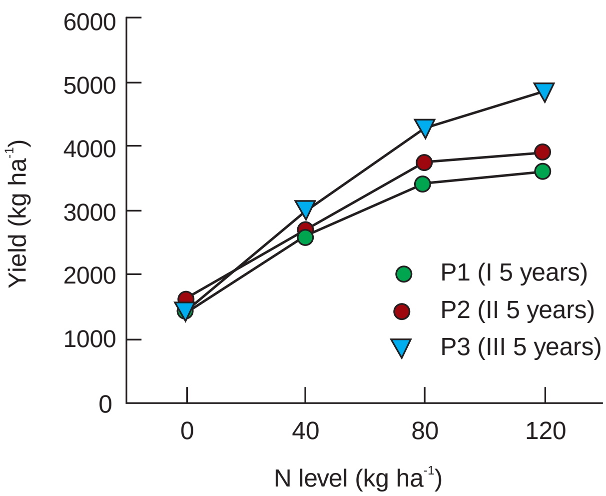

Figure 3. Response of wheat to nitrogen (N) at different periods of cropping in rice-wheat system at Pantnagar, India.

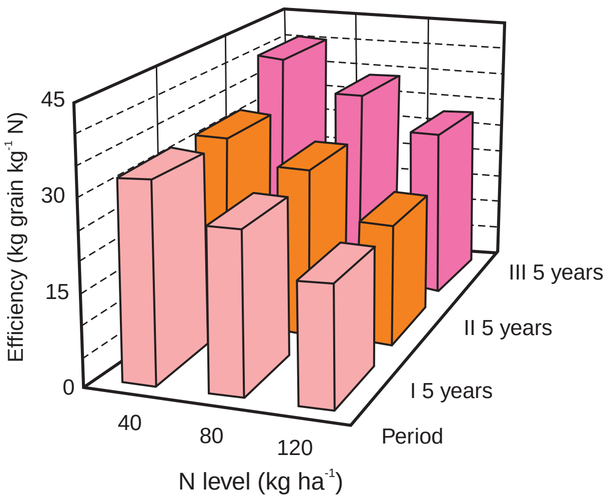

Figure 4. Agronomic efficiency of wheat at different nitrogen (N) levels at different periods of cropping in rice-wheat system at Pantnagar, India.

kg N increased mean wheat yield by 32.9 kg ha^{-1}, whereas it increased rice yield by 18.3 kg ha^{-1} only. Agronomic efficiency of wheat decreased with increasing N level; it was highest at 40 kg N ha^{-1}, followed by 80 and 120 kg N ha^{-1}. Agronomic efficiency of rice in later years was on par at all N levels. This shows that N supply was more limiting for rice and the law of diminishing return to applied N did not apply up to the highest N level (120 kg ha^{-1}). Confirmation of this observation can be seen in yields of rice attained at highest level, which has been mostly around 4.5 t ha^{-1} which is much less than the maximum expected yield (8 t ha^{-1}) for this agroecological area. However, such was not the case with wheat. Wheat yield at maximum N level is relatively higher than potential yields for this area (5 t ha^{-1}).

Linear response to fertilizer-N and similar agronomic efficiency at increasing N rates in rice and curvilinear response by wheat and declining agronomic efficiency at increasing N levels in wheat show less availability of applied N to rice. Numerous N-use experiments have shown that recovery of fertilizer-N normally ranges from 20% to 40% for rice (Peng and Guo 1991; Bajwa and Singh 1992; Mandal and Kar 1995) compared to 40–50% recovery by wheat (Sinha and Rai 1975). Through ^{15}N use in rice-wheat rotation, Shinde et al. (1985) recorded 23% uptake of fertilizer-N by rice and reported that 26% N was left in the root zone, and the following wheat removed 6.7% of the residual-N. Wheat removed 26% of applied fertilizer-N and the following rice utilized only 2.2% of the residual-N. Patil and Jain (1994) recorded 36% ^{15}N recovery by rice and of the remaining N, 3–5% was used by following wheat. Thus a large part of fertilizer N, particularly in rice, is lost by volatilization, leaching, and denitrification or left in the soil in forms not easily available to crops. There are reports that wetland rice depends more on soil-N even when it is adequately supplied with fertilizer N (Koyoma et al. 1973; Reddy and Patrick 1980; Shinde 1991). Hence the loss of soil-N supplying capacity is undesirable. Under the present experiment, more N losses are expected in rice season compared to wheat season. The soil of the experimental field is sandy loam in texture and, therefore, rate of infiltration of water is high, leading to high leaching losses of N. Further, due to high rate of infiltration, continuous submergence was not maintained. There were alternate regimes of submerged/saturated and unsaturated conditions. Unsaturated conditions favor nitrification of soil-N and NO_3-N is more likely to leach with next irrigation/rain. Severe N loss is reported in soil subjected to alternate draining and flooding (Wijler and Delwiche 1954; Macrae et al. 1968). Reddy et al. (1976) indicated that besides nitrification during the aerobic period and identification during the anaerobic period, NO_2-N formation and chemical decomposition may also be involved in N loss, especially for the more frequent changes in aerobic-anaerobic conditions.

Phosphorus. During the earlier years, there was no consistent response to P by either crop. Since 1992, there has been a consistent 10% increase in yield of both crops by P application (Table 1). The increase was statistically significant in all the 3 years for wheat, but only 2 of the 3 years for rice. The highest rice yield has been obtained with 40 kg P_2O_5 ha^{-1} in some years and with 80 kg P_2O_5 ha^{-1} in others. Initially the soil was rich in available P (916.4 mg Olsen P kg^{-1}), but continuous rice-wheat cropping depleted it to such an extent (12.9 mg kg^{-1}) that crops are now responding to its application.

Potassium. There was no response to K either by rice or wheat, as the exchangeable K level which was medium is being maintained

Table 1. Grain yields of rice and wheat under different levels of phosphorus (P) in rice-wheat system at Pantnagar, India.

P level	Rice yield ($kg\ ha^{-1}$)			Wheat yield ($kg\ ha^{-1}$)		
(Kg P_2O_5 ha^{-1})	1992	1993	1994	1992/93	1993/94	1994/95
0	3372	3734	3515	3754	4167	4277
40	3560	4036	3657	3898	4581	4324
80	3639	4004	3977	4126	4527	4565
CD (5%)	206	NS[1]	168	168	304	163

1. NS=not significant.

(1.2 mg kg^{-1}) in this mica rich soil even without K addition.

Yield trend

Yield trends have been worked out for N treatments only as P and K treatments did not affect yields in most of the years, except the last 3, when response to P was significant. Data have been pooled over P and K treatments. The productivity of rice without fertilizer application in the beginning of the experiment was 2.8 t ha^{-1} which declined over years. Declining trend in yield is also seen at 40 and 80 kg N ha^{-1}, though the rate is less at increasing N rates. Linear regression analysis of yield trend over years has shown that negative trend in yield in control plots and those receiving 40 kg N ha^{-1} was statistically significant. Yield change at 80 and 120 kg N ha^{-1} was not significant indicating yield stability at these rates. Declining yield trend at lower N levels could be related to reduced N supplying capacity of the soil over the years. At Varanasi, in a similar long-term experiment, there was a marginal declining yield trend even at 120 kg N ha^{-1} (Singh et al. 1988).

Wheat yield without fertilizer has remained nearly the same (1.4 t ha^{-1}) throughout. At 40 kg N level also, the yield did not change significantly, though higher yield was maintained. At higher levels of N (80 and 120 kg ha^{-1}), there was significant improvement in wheat yield over the years, particularly at 120 kg N ha^{-1}. This could be ascribed to improvement in management practices and change in variety. To begin with cv Sonalika was used in this experiment, which was later replaced by UP 2003. The results show sustainability of rice-wheat system at high N levels (120 kg ha^{-1}) to each crop, but to attain higher yields, N fertilizer at rates higher than 120 kg ha^{-1} would be required for each crop.

Nutrient balance and soil fertility status

Nutrient (NPK) uptake by rice as well as wheat was estimated by crop yield and nutrient content in plants. Nutrient balance has been worked out by the balance of annual addition and removal of NPK for their respective treatments as has been done earlier by Nambiar and Ghosh (1984) and Biswas and Benbi (1989). The balance of N was always negative (Table 2). In control plots, it was –73 kg ha^{-1} and at the highest N level of 120 kg ha^{-1} for each crop, the balance was –10.6 kg ha^{-1}. However, in this estimate N losses from soil have not been accounted for. If these losses by ammonia volatilization (Bouldin and Alimagno 1976; Freney et al. 1981), denitrification (Patrick and Tusneem 1972), and leaching (Harada and Kutsuna 1955) are considered, N utilization by crops is less than 50% of the applied fertilizer, and in that case N balance would be much more on the negative

Table 2. Mean annual nutrient balance in rice-wheat sequence at Pantnagar, India.

a. Nitrogen

Treatment ($kg\ ha^{-1}$)	Annual N addition ($kg\ ha^{-1}$)	N uptake ($kg\ ha^{-1}$)			Balance ($kg\ ha^{-1}$)
		Rice	Wheat	Total	
N0	0	42.0	31.0	73.0	–73.0
N40	80	68.2	68.3	136.5	–56.5
N80	160	95.6	100.3	195.9	–35.9
N120	240	130.6	120.6	250.6	–10.6

b. Phosphorus

Treatment ($kg\ ha^{-1}$)	Annual P addition ($kg\ ha^{-1}$)	P uptake ($kg\ ha^{-1}$)			Balance ($kg\ ha^{-1}$)
		Rice	Wheat	Total	
P0	0	21.0	15.5	37.3	–37.3
P40	35	23.0	18.8	41.8	–6.8
P80	70	24.1	19.2	43.3	+26.7

c. Potassium

Treatment ($kg\ ha^{-1}$)	Annual K addition ($kg\ ha^{-1}$)	K uptake ($kg\ ha^{-1}$)			Balance ($kg\ ha^{-1}$)
		Rice	Wheat	Total	
K0	0.0	74.0	103.3	177.3	–177.3
K40	33.3	87.6	115.3	202.9	–169.6

Table 3. Analysis of soil under different fertilizer treatments in rice-wheat system at Pantnagar, India.[1]

Fertilizer treatment ($kg\ ha^{-1}$)	pH (KCI 1:1)	Average Olsen P ($mg\ kg^{-1}$)	Exchangeable K ($meq\ 100g^{-1}$)	Total N (%)	OC (%)
Initial (1977)	7.1	16.4	0.228	0.104	0.99
Control (1995)	6.9	15.6	0.128	0.071	0.82
N40	7.0	17.2	0.128	0.071	0.77
N80	6.9	17.8	0.127	0.070	0.79
N120	6.9	16.5	0.116	0.068	0.76
P0	6.9	12.9	0.118	0.069	0.75
P40	7.0	17.2	0.126	0.069	0.77
P80	6.9	21.3	0.127	0.071	0.79
K0	6.9	15.9	0.121	0.068	0.76
K40	6.9	18.3	0.126	0.071	0.78

1. N=nitrogen, P=phosphorus; K=potassium; OC=organic carbon.

side. Hence, the N applied even at the highest rate (120 kg ha^{-1} for each crop) was not adequate to meet crop needs and higher N application is warranted to attain higher yields.

Phosphorus balance was negative in control plots (–37.3 kg P ha^{-1} yr^{-1}) as well as at low P level. However, at higher P level, there was positive P balance leaving soil rich in P which is reflected in soil analysis (Table 3). The K balance was negative in control as well as K applied plots, because K applied was only 33.3 kg ha^{-1} whereas crop removal was 202.9 kg ha^{-1} leaving a negative balance of 169.6 kg ha^{-1} (Table 2). In spite of such high negative balance of K over the years crops are not showing response to K application. It appears that K has been released adequately from K minerals, i.e., non-exchangeable forms of K. Similar observations were reported in the long-term experiment at Ludhiana, Punjab, India (Ganeshmurthy et al. 1985).

Analysis of surface soil (0–20 cm) was done after rice crop of 1995 for its pH and nutrient status. Soil pH remained nearly neutral and fertilizer treatments did not bring any change in it. The organic carbon content of soil has declined from its original level and now its status is highest in control plots. Similarly total N content has declined with little difference caused by fertilizer N. Available P content has declined in P control plots but it has built up in plots receiving higher P dose. The variation in K level is minimal.

References

Bajwa, M.S., and **Singh, B.** 1992. Fertilizer nitrogen management for rice and wheat crop. Fertilizer News 37(8):47–59.

Biswas, C.R., and **Benbi, D.K.** 1989. Long-term effects of manure and fertilizer on wheat based cropping system in semi-arid alluvial soils. Fertilizer News 34(4):33–38.

Bouldin, D.R., and **Alimagno, B.V.** 1976. NH_3 volatilization ftom IRRI paddies following broadcast application of fertilizer nitrogen. Terminal report as visiting scientist at IRRI. 51 pp. (Unpublished mimeo.)

Freney, T.R., Denmaead, O.T., and **Watanaoe.** 1981. Ammonia and nitrous oxide losses following applications of ammonium sulfate to flooded rice. Australian Journal of Agricultural Research 32:37–45.

Ganeshmurthy, A.N., Biswas, C.R., and **Singh, B.** 1985. Forms of potassium in the profiles of two long-term experiments in relation to K nutrition of crops. Journal of Agricultural Science, Cambridge 105:209–212.

Harada, T., and **Kutsuna, K.** 1955. Cation exchanges in soils. Bulletin of the National Institute of Agricultural Science, Japan, Serial B 5:1–26.

Koyoma, T., Chainek, C., and **Niamsrichand, N.** 1973. Nitrogen application technology for tropical rice as determined by field experiments using ^{15}N tracer technique. TARC Technical Bulletin 3:15–19.

Macrae, I.C., Ancajas, R.R., and **Sadanandan S.** 1968. The fate of nitrate nitrogen in some tropical submergence. Soil Science 105:327–334.

Mandal, D.K., and **Kar, S.** 1995. Water and nitrogen use by rice-wheat on Ultic Haplustalf. Journal of the Indian Society of Soil Science 43(1):9–13.

Nambiar, K.M., and **Ghosh, A.B.** 1984. Long-term fertilizer experiments in India. An overview. Fertilizer News 34(4):11–20.

Patil, K.P., and **Jain, J.M.** 1994. Utilization of recently immobilized fertilizer nitrogen by wheat as influenced by some organic chemicals in a rice-wheat sequence. Journal of the Indian Society of Soil Science 42(4):561–565.

Patrick, W.H. Jr., and **Tusneem, M.E.** 1972. Nitrogen losses from flooded soil. Ecology 53:735–737.

Peng, G.Y., and **Guo, Y.** 1991. Study of the efficiency and residual effect of N, P compound and N, P mixed fertilizers by ^{15}N tracer. Acta Agriculture University Pekinensis 17(2):91–96.

Reddy, K.R., and **Patrick, W.H. Jr.** 1980. Uptake of fertilizer nitrogen and soil nitrogen by rice using ^{15}N labelled nitrogen fertilizers. Plant and Soil 57:375–381.

Reddy, K.R., Patriek, W.H. Jr., and **Philipps, R.E.** 1976. Ammonium diffusion as a factor in nitrogen loss from flooded soil. Soil Science Society of America Journal 40:528–533.

Shinde, I.E. 1991. Residual nitrogen fertilizer in soil and its availability in rice-wheat cropping system. International Rice Research Newsletter 6(2):22–23.

Shinde, J.E., Krishnayya, K., Rao, K.V., and **Gandhi, G.** 1985. Transformation of ^{15}N labelled urea in rice-wheat cropping system. Plant and Soil 88:345–351.

Singh, Mahatim, Singh, M.P., Singh, Yashwant, and **Gupta, G.R.** 1988. Long range effect of continuous rice-wheat cropping under varying levels of N, P and K on yield and fertility status of soil with particular reference to iron. Journal of Plant Nutrition 11(6–11):1471–1478.

Sinha, M.N., and **Rai, R.K.** 1975. Use of ^{15}N wheat fertilization studies under field conditions. Journal of Nuclear Agriculture and Biology 4:49–51.

Wijler, J., and **Delwiche, C.C.** 1954. Investigations on the denitrifying process in soil. Plant and Soil 5:155–169.