Long-term Effects of Fertilizers on Rice-Wheat-Cowpea Productivity and Soil Properties in a Mollisols

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Abstract

In a long-term fertilizer experiment conducted on an Aquic Hapludoll under rice-wheat-cowpea system a declining trend was observed in rice productivity. Response to N, Zn, and farmyard manure (FYM) was quite marked both in rice and wheat. In the control, the initial status of 1.48% organic carbon reduced to one-third in two decades. However, use of 100% NPK + FYM restored the original level. Addition of 150% NPK and 100% NPK + FYM led to considerable build-up in the availability of P, K, and S. Application of 100% NPK along with FYM or Zn is suggested, to stop deterioration in crop productivity and soil fertility.

Introduction

With introduction of high-yielding varieties of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.), there has been a significant change in the cropping patterns in north India, wherein most of the rice area is normally rotated with wheat. Both these crops are heavy nutrient feeders and their intensive cropping leads to large withdrawal of plant nutrients from soil, thereby accentuating the problem of nutrient disorders and affecting crop yields. Therefore, soil-fertility management is of utmost importance. In this context long-term effects of continuous fertilizer [NPK (nitrogen, phosphorus, potassium)] use on soil fertility and productivity need to be given due consideration for the nutrient management in a cropping system. The results of a 20-year study on crop productivity and the effects of long-term rice-wheat cropping on soil fertility are presented.

Materials and Methods

The permanent field experiment of the All-India Coordinated Research Project on Long-term Fertilizer was started in 1971 with rice-wheat-cowpea (*Vigna unguiculata* (L.) Walp.) sequence at Pantnagar situated in the foothills of the Himalayas in northern India (29° N, 79°3’ E, and 283 m above mean sea level) having humid subtropical climate (Nambiar and Ghosh 1984). The experimental soil is silty clay loam, Aquic Hapludoll, rich in organic matter with a slightly alkaline pH and dominated by chlorite and illite minerals (Deshpande et al. 1971).

Initially, the soil had 1.48% organic carbon with a status of 392, 18, and 125 kg ha^{-1} of alkaline $KMnO_4$-N, Oslen's P, and NH_4OAc-K, respectively and 2.7, 29.5, 26.8, and 2.9 mg kg^{-1} of DTPA-extractable zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) respectively (Nand Ram 1995).

Twelve treatments consisting of 50, 100, and 150% of the recommended fertilizer dose were quadruplicated in randomized block design. The individual plot size was 25 m × 12 m. The treatments were:

T1 50% NPK

T2 100% NPK

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T3 150% NPK

T4 100% NPK + hand weeding

T5 100% NPK + Zn

T6 100% NP

T7 100% N

T8 100% NPK + farmyard manure (FYM)

T9 100% NPK – sulfur (S)

T10 Biofertilizer (rice–Azolla, wheat-*Azotobacter*, cowpea-*Rhizobium*).

T11 Control

T12 Fallow

Except T4 and T11, weeds in all other treatments were chemically controlled. In T8, FYM was incorporated @ 15 t ha^{-1} on dry-weight basis once a year before wheat sowing, whereas in T5, Zn was foliar sprayed both on rice and wheat by dissolving 5 kg $ZnSO_4.7H_2O$ together with 2.5 kg $CaCO_3$ in 800 L of water for use over 1 ha.

At 100% NPK (optimal) fertilizer dose, rates of N, P, and K were 120, 26, and 37 kg ha^{-1} for rice and 120, 26, and 37 kg ha^{-1} for wheat respectively. Sources of N and K were urea and muriate of potash respectively. Phosphorus was added as single superphosphate but in S-free treatment (100% NPK–S), its source was diammonium phosphate.

In the cropping sequence of rice-wheat-cowpea, high-yielding varieties of crops were grown. Normally, 3-week-old seedlings of rice were transplanted in mid-July, wheat was sown in first week of December, and cowpea in second week of May, every year. In rice and wheat, half dose of N and full dose of P and K were applied basal at the time of transplanting or sowing, while the remaining N was top-dressed in two equal doses. Cowpea fodder was grown as residual crop without using any fertilizer. Crops were irrigated whenever needed and standard agronomic practices were adopted thoroughout the crop seasons.

At harvest, grain and straw yields of rice (rough) and wheat and fodder yield of cowpea were recorded. Plant samples were collected for chemical analysis. Surface soil samples collected from each plot every year after cowpea harvest were analyzed for organic carbon and the available macro- and micronutrients.

Results and Discussion

Crop production

The average yields of rice grain, wheat grain, and cowpea fodder over 20 years (1972–92) are given in Table 1. The highest crop yield of 6.41, 4.60, and 2.47 t ha^{-1} of rice grain, wheat grain, and cowpea fodder respectively was recorded by integrated use of FYM and optimal NPK (100% NPK + FYM), followed by 100% NPK + Zn. Continuous cropping without any fertilizer or manure resulted in the lowest production of 3.74, 1.71, and 1.86 t ha^{-1} of rice grain, wheat grain, and cowpea fodder respectively during the corresponding period (Table 1).

The grain yields of rice and wheat over two decades (1972–92 with 3-year rolling average were calculated. Yield trends showed a declining pattern for rice grain. The mean production of rice grain during first 3-year cropping period (1972–75) was 5.78, 7.35, 7.19, 7.69, and 8.47 t ha^{-1} which reduced to 1.80, 3.68, 3.88, 4.10, and 4.76 t ha^{-1} during last 3-year cropping period (1989–92) in control, 100% N, 100% NP, 100% NPK, and 100% NPK + FYM treatments respectively.

Yield trends for wheat grain showed lesser fluctuations than that for rice. The mean grain yield of wheat during the first 3 cropping cycles

Table 1. Mean crop yield (t ha^{-1}) over 20 years during 1972–92 at Pantnagar, India.

Treatment[1]	Rice grain (rough)	Wheat grain	Cowpea fodder
50% NPK	5.02	3.13	1.93
100% NPK	5.67	3.97	2.36
150% NPK	5.92	4.38	2.32
100% NPK + HW	5.44	4.16	2.34
100% NPK + Zn	5.95	4.28	2.37
100% NP	5.24	3.90	2.21
100% N	5.25	3.85	2.11
100% NPK + FYM	6.41	4.60	2.47
100% NPK – S	5.41	3.82	2.41
Biofertilizer	3.80[2]	2.22[2]	2.91[3]
Control	3.74	1.71	1.86

1. NPK=nitrogen, phosphorus, potassium; HW=hand weeding; Zn=zinc; FYM=farmyard manure; S=sulfur.
2. Mean of 14 crops.
3. Mean of 7 crops.

(1972–75) was 1.98, 4.50, 4.37, 4.41, and 4.71 t ha^{-1} and during the last 3-year cropping period (1989–92) was 1.25, 3.70, 3.91, 4.04, and 4.81 t ha^{-1} in control, 100% N, 100% NP, 100% NPK, and 100% NPK + FYM treatments respectively.

Yield response

Response to applied N was remarkable both in rice and wheat, the yields being 1.57 and 2.52 t ha^{-1} in the first 3-year cropping period (1972–75) and 1.88 and 2.45 t ha^{-1} in the last 3-year cropping period (1989–92) respectively. Wheat responded more to N than rice, indicating the latter crop to be an inefficient N user among cereals. Due to high availability of initial soil P (18 kg ha^{-1}), no response to P was noted in any of the crops during initial years. However, in recent years an increasing trend for P response (0.2 t ha^{-1}) was noted with the depletion of available soil P. Rice responded to K which ensures adequate absorption owing to its restricted root system under submergence, whereas wheat met its K needs from native soil K. Indirect addition to S through single superphosphate did not show any significant effect on crop yields over the years.

Declining trend in the grain yield of rice and wheat was observed after 12 annual cropping cycles (rice-wheat-cowpea fodder) in the absence of Zn application. Incidence of khaira (a Zn deficiency disorder) was prevalent in rice with more severity at 150% NPK. Incorporation of either Zn or FYM along with optimal NPK controlled khaira (Nand Ram 1996). During 1989–92 the productivity of rice and wheat was improved by 0.60 and 0.64 t ha^{-1} respectively with Zn over optimal NPK. Deterioration in soil productivity occurred due to drastic decrease in available soil Zn from 2.7 to 0.8 mg kg^{-1} soil in 20 years. Amending the soil with FYM resulted in a mean response of 0.78 and 0.30 t ha^{-1} during the first 3 years and 0.66 and 0.77 t ha^{-1} during the last 3 years for rice and wheat grain respectively. It is attributed to enhanced availability of plant nutrients and improvement in soil physical properties by FYM incorporation (Rawat et al. 1996).

Soil organic matter

Initially soil organic carbon was 1.48%. In general, with continuous cropping of rice-wheat-cowpea for 8–10 years, a declining trend in soil organic carbon was observed. After 20 years, maximum loss of 67% in the initial level was noted in the control where neither fertilizers nor manures were applied since the inception of the experiment. With balanced use of NPK (10% NPK) the loss was minimized to 43%. However, the original status of organic carbon was restored by use of 100% NPK + FYM.

As this experiment was laid out on a virgin soil, not much change in soil organic matter was observed in the initial years. Later on due to intensive cultivation over the years, the rate of decline was faster (Alexander 1977). Moreover, the reduction in soil organic carbon is also due to loss of soil aggregation (Rawat et al. 1996), which makes a portion of the organic matter accessible to microbial decomposition, and too little return of organic materials to the soil. The FYM is very effective in maintaining levels of soil organic matter because it degrades slowly.

Soil nutrient status

Macronutrients. The patterns of available soil N, P, and K were affected by continuous fertilizer use. Initially alkaline $KMnO_4$ extractable N was 392 kg ha^{-1}. Over the years, a declining trend in N availability was observed. Even addition of 150% NPK and 100% NPK + FYM did not maintain its original status. In control, it decreased considerably to 182 kg ha^{-1}. The decline in available N is presumably concomitant with the decline in soil organic matter level. The N-supplying capacity of control treatment decreased from 5.78 t ha^{-1} to 1.80 t ha^{-1} for rice and from 1.98 t ha^{-1} to 1.25 t ha^{-1} for wheat in two decades. The loss in soil N seems to be associated with its solubilization and consequent leaching particularly under submerged conditions of rice (Nambiar 1994).

The initial level of Olsen's P (18 kg ha^{-1}) was in medium fertility class (9.8–24.4 kg ha^{-1}) for P availability. Continuous cropping of rice-wheat-cowpea without adding P for two decades decreased its fertility class to low both in the control (7.5 kg ha^{-1}) and 100% N (8.8 kg ha^{-1}) treatments. Addition of 100% NP and 100% NPK maintained the same medium fertility class. However, by applying 100% NPK + FYM and 150% NPK significant build-up in P availability was noted as the soil status rose to high fertility class under both these treatments.

The initial level of NH_4OAc-extractable K was 125 kg ha^{-1}. Application of N alone (100% N) or along with P (100% NP) decreased the soil K availability over the years, as K was omitted from the fertilizer schedule in these treatments. Regular dressing of K in the form of 100% NPK was able to maintain initial level, whereas a considerable build-up in K availability was observed by adding 100% NPK + FYM and 150% NPK over the initial status during 20 years.

Sulfur. The status of total and organic S reduced to about half with the use of S-free NPK fertilizers, whereas S-bearing fertilizers led to considerable build-up. Addition of S indirectly through single superphosphate raised the level of total S by 396, 563, and 859 mg kg^{-1} and that of organic S by 365, 513, and 705 mg kg^{-1} at 50, 100, and 150% NPK respectively compared with the control. The concentration of available S extracted by $Ca(H_2PO_4)_2$, heat-soluble method, and $CaCl_2$ was 19.2, 14.6, and 9.1 mg kg^{-1} in S-free (100% NPK-S) treatment and 62.2, 56.2, and 44.8 mg kg^{-1} in S-containing (100% NPK+S) treatment respectively (Table 2) (Tiwari et al. 1995).

Table 2. Effect of continuous fertilizer use on available sulfur (S) (mg kg^{-1}) in soil at Pantnagar, India.

Treatment[1]	$Ca(H_2PO_4)_2$-S	Heat-soluble S	$CaCl_2$-S
Control	21.6	20.0	13.3
100% NPK – S	19.2	14.6	9.1
50% NPK + S	44.4	36.2	32.8
100% NPK + S	62.2	56.2	44.8
150% NPK + S	93.4	85.2	74.7
100% NPK + S + FYM	64.7	60.5	48.1
CD (P=0.05)	5.0	4.1	4.3

1. NPK=nitrogen, phosphorus, potassium; FYM=farmyard manure.

Micronutrients. The data on changes in the levels of available soil Zn, Fe, Mn, and Cu extractable with DTPA after two decades of intensive cropping of rice-wheat-cowpea are given in Table 3. Zinc availability over the years showed a declining trend. In the absence of Zn application, DTPA-extractable Zn decreased from the initial level of 2.7 mg kg^{-1} to 0.80 and 0.63 mg kg^{-1} at 100% NPK and 150% NPK treatments respectively. These values are below the critical level of 1.6 mg kg^{-1} reported for Mollisols (Gangwar and Chandra 1976), indicating the need for applying Zn.

Foliar spray of Zn (100% NPK + Zn) did not increase the level of available Zn (1.2 mg kg^{-1}). Incorporation of FYM along with optimal NPK (100% NPK + FYM) maintained the availability of Zn in soil comparable to that of Zn spray. It may be attributed to its direct contribution to nutrient pool and increased availability either through complexion (Nand Ram and Raman 1984) or mobilization of native Zn (Nand Ram and Verloo 1985).

Not much change in the availability of Fe, Mn, and Cu was observed. The level of these micronutrients is still well above the critical levels of 4.5, 2, and 0.2 mg kg^{-1} for Fe, Mn, and Cu respectively generally reported in India (Gupta 1993).

Conclusion

Decrease in crop productivity over the years with intensive cropping could be largely traced in the deficiency of N and Zn, probable toxicity of Fe

Table 3. DTPA-extractable micronutrients (mg kg^{-1}) after 20 years of rice-wheat-cowpea cropping at Pantnagar, India.[1]

Treatment	Zn	Fe	Mn	Cu
Control	0.88	23	18	3.5
100% NPK	0.80	37	24	4.3
100% NPK + Zn	1.20	35	23	4.8
100% NPK + FYM	1.10	42	29	5.5
150% NPK	0.63	41	28	4.4
CD (P = 0.05)	0.04	2.4	2.7	0.4

1. Zn=zinc; Fe=iron; Mn=manganese; Cu=copper; NPK=nitrogen, phosphorus, potassium; FYM=farmyard manure.

and Mn, and nutrient imbalance due to antagonism. Corrective measures such as curtailing P application where the build-up is considerably high and raising the quantities of FYM and Zn are needed.

References

Alexander, M. 1977. Introduction to soil microbiology. New York, USA: John Wiley & Sons.

Deshpande, S.B., Fehrenbacher, J.B., and **Ray, B.W.** 1971. Mollisols of Tarai region of Uttar Pradesh, Northern India - II. Genesis and classification. Geoderma 6:195–201.

Gangwar, M.S., and **Chandra, S.K.** 1976. Estimation of critical limits for zinc in rice soils. Communications in Soil Science and Plant Analysis. 7:295–310.

Gupta, V.K. 1993. Soil analysis for available micronutrients. *In* Methods of analysis of soils, plants, waters and fertilizers (Tandon, H.L.S, ed.). New Delhi, India: Fertilizer Development and Consultation Organization.

Nambiar, K.K.M. 1994. Soil fertility and crop productivity under long-term fertilizer use in India. New Delhi, India: Indian Council of Agricultural Research.

Nambiar, K.K.M., and **Ghosh, A.B.** 1984. Highlights of research of long-term fertilizer experiment in India (1971–82). LTFE Research Bulletin No. 1. New Delhi, India: Indian Agricultural Research Institute.

Nand Ram. 1995. Long-term effects of fertilizers on crop production and soil properties in Mollisol. Technical Research Bulletin 124. Pantnagar, India: Govind Ballabh Pant University of Agriculture and Technology.

Nand Ram. 1996. Amelioration of zinc stress by farmyard manure in rice-wheat-cowpea system. Acta Agronomica Hungarica 44:35–39.

Nand Ram, and **Raman, K.V.** 1984. Evaluation of zinc humate and fulvate as sources of zinc for rice. Agrochimica 28:96–101.

Nand Ram, and **Verloo, M.** 1985. Effect of various organic materials on the mobility of heavy metals in soil. Environmental Pollution (B) 10:241–248.

Rawat, M.S., Tripathi, R.P., and **Nand Ram.** 1996. Long-term effect of puddling and fertilizer use in rice-wheat-cowpea on structural properties of soil. Journal of the Indian Society of Soil Science 44:364–368.

Tiwari, H.C., Gangwar, M.S., and **Nand Ram.** 1995. Effect of continuous cropping and fertilization on the total organic and available sulphur in a Hapludoll. Tropical Agriculture 72: 274–276.