# Effects of Long-term Application of Fertilizers and Manure on Soil Fertility and Crop Yields in Rice-Rice-Wheat Cropping System in Nepal

**A P Regmi[1], S P Pandey[1], and D Joshy[2]**

## Abstract

A long-term soil fertility experiment has been conducted at the Regional Agricultural Research Station, Bhairawaha, Nepal to evaluate effects of long-term application of fertilizers and manure on soil fertility in a rice-rice-wheat cropping system. Nine fertilizer treatments including farmyard manure (FYM) were tested. A sharp decline in yield was observed in minus phosphorus (P) treatments. Yield decline was severe in early rice compared to normal rice and wheat. In minus P treatment, yield reduced to zero by the 5th year in early rice and by 18th year in normal rice. Yield reduction in the minus potassium (K) treatments was also observed in all 3 crops. Response of N was not visible in the absence of P and K. Thus limitation in P and K supply reduced grain yields of rice and wheat. FYM improved almost all soil properties except exchangeable K. Despite improvement of soil properties in FYM plots, yield could not be sustained. Application of P and K partially reversed original yield in P- and K-deficient plots.

## Introduction

The rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system is practiced in about 0.6 million ha in Nepal, extending from Terai to sub-temperate mid-hill region. Rice-rice-wheat pattern is practiced in subtropical Terai and lower foot hill river basins, where perennial irrigation is available. There is a very limited rice area left for expansion and farmers are compelled to produce more yields from the same area. Considering the potentiality of irrigable land and increasing requirements of food, and rice being the most favored food in Nepal, the rice-rice-wheat pattern is likely to extend considerably in future. This intensive cropping will remove greater amount of nutrients from soil, which may lead to severe nutrient deficiencies if not replenished properly. An imbalanced fertilizer application may disturb nutrient status of soil and the soil may become non/less productive. The country-wide promotion of fertilizers after 1960s necessitated a scientific basis of their use. As a result, a long-term soil fertility experiment was established with the following objectives:

- To study effects of continuous use of mineral fertilizers and organic manure on crop yields and soil properties;
- To study response of nitrogen (N) with and without phosphorus (P) and/or potassium (K);
- To study if P and K become limiting factors on rice-rice-wheat system in the long run; and
- To study the residual effect of left over crop residues on soil fertility.

1. Regional Agricultural Research Station, Bhairawaha, Nepal. 2. Nepal Agriculutral Research Council, Kathmandu, Nepal.

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## Materials and Methods

The experiment has been conducted since 1978/79 at the Regional Agricultural Research Station, Bhairawaha. This research station is located at 27°32' N and 83°28' E on an elevation of 120 m above sea level in western Terai (an extension of the Indo-Gangetic Plain) of Nepal. The temperature ranges from a minimum of 8.5°C in January to 36.2°C in May with a mean annual total rainfall of 1,687 mm (25-year average).

The soil of the experimental field is a silt loam with pH 8.0, organic carbon 1.03%, Olsen P 9.8 $\mu g\ g^{-1}$, and exchangeable K 3.2 meq $kg^{-1}$ soil. Groundwater table often reaches close to surface in rainy season and it remains at 50–60 cm and 80–90 cm in early and later growth stages of wheat respectively. The soils are classified as Typic Haplaquepts (calcareous). The surface soils of the station have a bulk density of 1.6 g $cm^{-3}$ with a hard pan below plow layer. The soils are generally considered good for rice cultivation but found less satisfactory for wheat. The soils tend to pond after rain or irrigation.

The experiment has a randomized complete block design with 9 different treatments (T1 to T9) replicated 3 times (Table 1). The plot size was 6 m × 4 m up to 1990. In 1990 (from 36th crop of early rice), plots were split into two plots (4 m × 3 m each) and $ZnSO_4$ at the rate of 25 kg $ha^{-1}$ was applied randomly to early rice (once only). Since then treatments were modified periodically leaving 1/2 of the

**Table 1. Original and modified treatments of the long-term soil fertility experiment at Bhairawaha, Nepal.[1]**

| Treatment | Original (O) (1978–1990) | | | | Modified (M) (1991) | | | | Modified (M) (1995 onward) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Crop | N | P | K | Crop | N | P | K | Crop |
| T1 | 0 | 0 | 0 | R&W | | | | | 100 | 22 | 83 | R&W |
| T2 | 100 | 0 | 0 | R&W | 100 | 13 | 25 | R | | | | |
| | | | | | 100 | 17 | 25 | W | | | | |
| T3 | 100 | 13 | 0 | R | | | | | 100 | 13 | 25 | R |
| | 100 | 17 | 0 | W | | | | | 100 | 17 | 25 | W |
| T4 | 100 | 0 | 25 | R&W | 100 | 43 | 25 | ER | 100 | 13 | 25 | R |
| | | | | | | | | (once) | 100 | 17 | 25 | W |
| T5 | 100 | 13 | 25 | R | | | | | 100 | 13 | 83 | R |
| | 100 | 17 | 25 | W | | | | | 100 | 17 | 83 | W |
| T6 | 100 | 0 | 0 | R | 100 | 13 | 25 | ER | | | | |
| | 100 | 17 | 25 | W | | | | | | | | |
| T7 | 50 | 0 | 0 | R&W | 50 | 9 | 0 | R&W | | | | |
| T8 | 50 | 9 | 0 | R&W | | | | | 50 | 9 | 17 | R&W |
| T9 | 0 | 0 | 0 | R&W | 50 | 0 | 0 | R&W | 50 | 0 | 42 | R&W |
| | (FYM 10 t $ha^{-1}$) | | | | (FYM 10 t $ha^{-1}$) | | | | FYM 10 t $ha^{-1}$ | | | |

1. NPK (kg $ha^{-1}$): N=nitrogen; P=phosphorus; K=potassium; R=rice; W=wheat; ER=early rice; FYM=farmyard manure.

plot as original. Spacing was 20 cm × 20 cm for rice and wheat was sown in rows 25 cm apart. The dates of seeding/transplanting of varieties of rice and wheat crops used in different years are given in Tables 2, 3, and 4.

Half of the N and full P and K were basally applied prior to planting. Remaining half of the N was top-dressed at 21–25 days after seeding in wheat and 25–30 days after transplanting in rice. Farmyard manure (FYM) was applied 4–7 days before seeding/ transplanting. Irrigation was given to maintain submerged condition from transplanting until physiological maturity in rice. In wheat, 2 irrigations–at crown root initiation stage and at booting stage–were applied. Hand weeding was done to manage weeds and plant protection measures were adopted as needed to control pests. Crops were harvested close to ground level and straw was removed from the field except in T7 and T8 where crops were harvested at 30 cm above ground level and straw was removed and stubbles were incorporated into the soil.

Grain yields of 18 years (from original treatments) were analyzed by combined analysis by MSTATC package using Model 15 for individual crop and Model 19 for total crop yield. Regression analysis was done to discriminate effects of treatment in yield over

**Table 2. Date of seeding and transplanting of early rice varieties in the long-term soil fertility experiment at Bhairawaha, Nepal.**

| Crop | Year | Variety | Date of seeding | Date of transplanting |
|---|---|---|---|---|
| 3rd | 1979/80 | Chandina | 15 Mar 1979 | 11 Apr 1979 |
| 6th | 1980/81 | CH45 | 16 Apr 1980 | –[1] |
| 9th | 1981/82 | CH45 | 5 Mar 1981 | 3 Apr 1981 |
| 12th | 1982/83 | Laxmi | NA[2] | 16 Apr 1982 |
| 15th | 1983/84 | Laxmi | 8 Mar 1983 | 25 Apr 1983 |
| 18th | 1984/85 | CH45 | 28 Feb 1984 | 11 Apr 1984 |
| 21st | 1985/86 | CH45 | NA | 16 Apr 1985 |
| 24th | 1986/87 | CH45 | 7 Mar 1986 | 8 Apr 1986 |
| 27th | 1987/88 | CH45 | 17 Mar 1987 | 19 Apr 1987 |
| 30th | 1988/89 | CH45 | 6 Mar 1988 | 12 Apr 1988 |
| 33rd | 1989/90 | CH45 | 16 Mar 1989 | 11 Apr 1989 |
| 36th | 1990/91 | CH45 | 20 Mar 1990 | 19 Apr 1990 |
| 39th | 1991/92 | CH45 | 20 Mar 1991 | 22 Apr 1991 |
| 42nd | 1992/93 | CH45 | 3 Mar 1992 | 15 Apr 1992 |
| 45th | 1993/94 | CH45 | 12 Mar 1993 | 14 Apr 1993 |
| 48th | 1994/95 | CH45 | 8 Mar 1994 | 12 Apr 1994 |
| 51st | 1995/96 | CH45 | 15 Mar 1995 | 22 Apr 1995 |
| 54th | 1996/97 | CH45 | 13 Mar 1996 | 19 Apr 1996 |

1. Direct seeding.

2. NA=Data not available.

**Table 3. Date of seeding and transplanting of normal rice varieties in the long-term soil fertility experiment at Bhairawaha, Nepal.**

| Crop | Year | Variety | Date of seeding | Date of transplanting |
|---|---|---|---|---|
| 1st | 1978/79 | Sabitri | 16 Jun 1978 | 1 Jul 1978 |
| 4th | 1979/80 | Chandina | 22 Jul 1979 | 12 Aug 1979 |
| 7th | 1980/81 | Laxmi | 18 Jun 1980 | 7 Aug 1980 |
| 10th | 1981/82 | Laxmi | 7 Jul 1981 | 29 Jul 1981 |
| 13th | 1982/83 | Laxmi | NA[1] | 8 Aug 1982 |
| 16th | 1983/84 | Laxmi | NA | 24 Aug 1983 |
| 19th | 1984/85 | Durga | NA | 26 Jul 1984 |
| 22nd | 1985/86 | Bindeshwari | 2 Jul 1985 | 5 Aug 1985 |
| 25th | 1986/87 | CH45 | 2 Jul 1986 | 27 Jul 1986 |
| 28th | 1987/88 | Laxmi | 1 Jul 1987 | 3 Aug 1987 |
| 31st | 1988/89 | Janaki | 26 Jun 1988 | 27 Jul 1988 |
| 34th | 1989/90 | Makwanpur-1 | 30 Jun 1989 | 3 Aug 1989 |
| 37th | 1990/91 | Janaki | 26 Jun 1990 | 30 Jul 1990 |
| 40th | 1991/92 | Janaki | 2 Jul 1991 | 4 Aug 1991 |
| 43rd | 1992/93 | Janaki | 26 Jun 1992 | 26 Jul 1992 |
| 46th | 1993/94 | Sabitri | 22 Jun 1993 | 22 Jul 1993 |
| 49th | 1994/95 | Sabitri | 22 Jun 1994 | 28 Jul 1994 |
| 52nd | 1995/96 | Sabitri | 20 Jun 1995 | 3 Aug 1995 |
| 55th | 1996/97 | Sabitri | 29 Jun 1996 | 4 Aug 1996 |

1. NA=Data not available.

years. Cluster analysis was done to group long-term treatments. After 13 years, soil samples were taken from 0–15 cm depth and were analyzed adopting the following procedures:

1. Soil pH was determined on 1:1 soil-water suspension.
2. Soil organic matter was determined by wet digestion with $K_2Cr_2O_7$ and concentrated $H_2SO_4$ and titrated with standard $FeSO_4$ solution.
3. Total N was analyzed by Kjeldahl analysis using Tecator Kjeltec auto system.
4. Total P was determined by digestion with 2:1 mixture of 60% $HClO_4$ and concentrated $H_2SO_4$.
5. Available P (Olsen P) was determined by sodium bicarbonate extraction.
6. Exchangeable $K^+$, $Na^+$, $Mg^{++}$, and $Ca^{++}$ or total exchangeable bases were determined from the $NH_4OAC$ filtrate using atomic absorption spectrophotometer (Mg by absorption and rest by emulsion).
7. Hot water was used as extractant and curcumin was used to determine available boron.
8. Cation exchange capacity (CEC) was determined as $NH_4$ equivalents using

**Table 4. Date of seeding of wheat varieties in the long-term soil fertility experiment at Bhairawaha, Nepal.**

| Crop | Year | Variety | Date of seeding |
|---|---|---|---|
| 5th | 1979/80 | RR 21 | 26 Nov 1979 |
| 8th | 1980/81 | RR 21 | 1 Dec 1980 |
| 11th | 1981/82 | Lumbini | 19 Nov 1981 |
| 14th | 1982/83 | Lumbini | 2 Dec 1982 |
| 17th | 1983/84 | Lumbini | 21 Dec 1983 |
| 20th | 1984/85 | Siddhartha | 19 Nov 1984 |
| 23rd | 1985/86 | Nepal-297 | 4 Dec 1985 |
| 26th | 1986/87 | Nepal-297 | 8 Dec 1986 |
| 29th | 1987/88 | Nepal-297 | 18 Nov 1987 |
| 32nd | 1988/89 | Nepal-297 | 5 Dec 1988 |
| 35th | 1989/90 | Nepal-297 | 22 Dec 1989 |
| 38th | 1990/91 | Nepal-297 | 24 Nov 1990 |
| 41st | 1991/92 | Nepal-297 | 20 Nov 1991 |
| 44th | 1992/93 | Nepal-297 | 1 Dec 1992 |
| 47th | 1993/94 | Nepal-297 | 8 Dec 1993 |
| 50th | 1994/95 | Nepal-297 | 6 Dec 1994 |
| 53rd | 1995/96 | Nepal-297 | 14 Dec 1995 |
| 56th | 1996/97 | Nepal-297 | 16 Dec 1996 |

autoanalyzer after saturation with 1N $NH_4OAC$ at pH 7.0, followed by filtration, washing with acidified NaCl, and subsequent distillation.

## Results and Discussion

Long-term application of mineral fertilizers significantly affected grain yield (Table 5). Grain yield of both rice crops decreased over years specially in minus P treatments.

### Yield trends of rice

Grain yield of early rice decreased sharply to zero by 5th year in the minus P treatment with recommended levels of N and K (T4, 100:0:25 NPK). After the 5th year, the yields from all minus P treatments T1, T2, and T4 dropped to zero (Fig. 1) indicating an acute deficiency of available P in the soil. In normal rice, the yield decline trend was less severe compared to the early rice, where yield reduced to zero by the 18th year in all minus P treatments (Fig. 2). In early rice, all P receiving treatments showed similar trends and were distinctly higher in minus P treatments. Trends are similar but magnitude is less in normal rice. Higher yield in normal rice in minus P treatments could be due to better availability of P because of submergence of soil for long duration (early + normal rice period) (Ponnamperuma 1972) and seasonal variability which needs to be investigated. It is noted that the grain yields of early rice had gradually declined till the 8th year even in T5 (100:13:25 NPK for rice; 100:17:25 NPK for wheat) that received recommended dose of

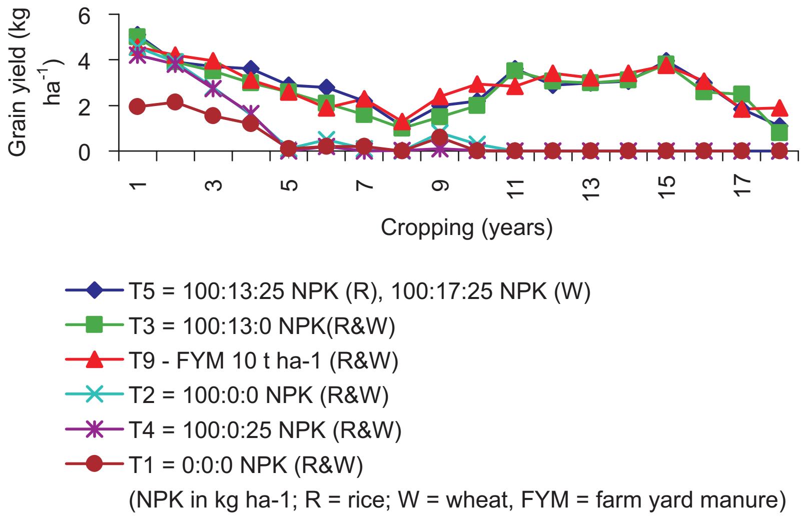


**Figure 1. Effect of long-term fertilization on the yield of early rice at Bhairwaha, Nepal.**

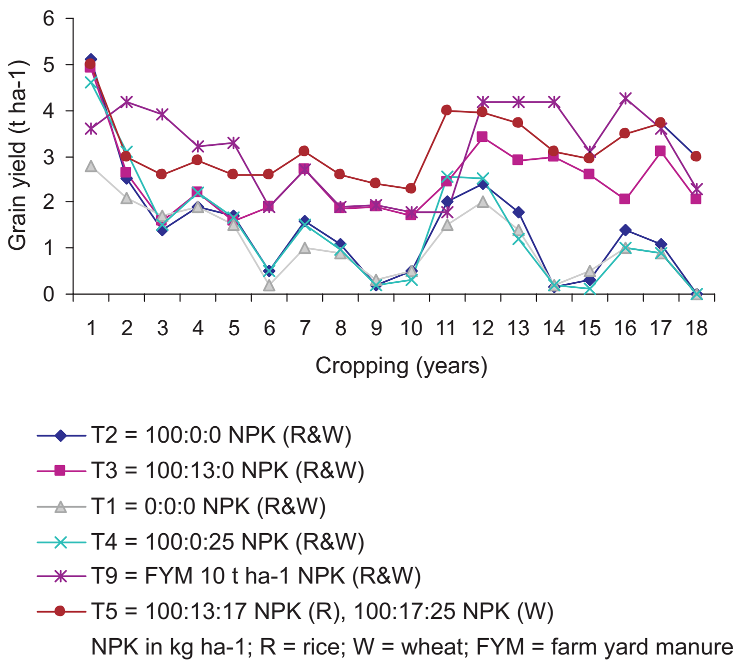


**Figure 2. Effect of long-term fertilization on the yield of normal rice at Bhairawaha, Nepal.**

NPK. After the 8th year of the yield depression, it again inclined up to 11th year and remained at that level for four years; later, it again continued to decline up to 18th year. The minus K treatment T3 (100:13:0 NPK for rice; 100:17:0 NPK for wheat) and T9 (FYM 10 t $ha^{-1}$) also followed similar trends (Fig. 1). Thus, results clearly show that neither recommended dose of NPK (T5) nor FYM (T9) at present level of supply could sustain initial level of productivity. This is one of the important points to be considered for future

**Table 5. Mean grain yield of rice and wheat as affected by the long-term application of fertilizers and manure in rice-rice-wheat system at Bhairawaha, Nepal.**

| Treatment | Fertilizer (kg ha$^{-1}$) to rice[1] | | | Fertilizer (kg ha$^{-1}$) to wheat | | | Grain yield[2] (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | Early rice | Normal rice | Wheat |
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 433 f | 1128 e | 546 f |
| T2 | 100 | 0 | 0 | 100 | 0 | 0 | 799 d | 1439 d | 610 f |
| T3 | 100 | 13 | 0 | 100 | 17 | 0 | 2649 b | 2519 e | 1236 e |
| T4 | 100 | 0 | 25 | 100 | 0 | 25 | 700 de | 1395 d | 638 f |
| T5 | 100 | 13 | 25 | 100 | 17 | 25 | 2846 a | 3143 a | 2332 a |
| T6 | 100 | 0 | 0 | 100 | 17 | 25 | 2183 c | 2146 c | 2014 c |
| T7 | 50 (+30 cm stubble) | 0 | 0 | 50 (+30 cm stubble) | 0 | 0 | 612 e | 1220 e | 533 f |
| T8 | 50 (+30 cm stubble) | 9 | 0 | 50 (+30 cm stubble) | 9 | 0 | 2066 c | 2583 b | 1427 b |
| T9 (FYM 10 t ha$^{-1}$) | 0 | 0 | 0 | 0 (FYM 10 t ha$^{-1}$) | 0 | 0 | 2903 a | 3237 a | 2211 b |
| CV (%) | | | | | | | 24 | 13.2 | 20.3 |
| Year | | | | | | | HS | HS | HS |
| Treatment | | | | | | | HS | HS | HS |
| Year × Treatment | | | | | | | HS | HS | HS |

1. Both early and normal rice; NPK=nitrogen, phosphorus, potassium; FYM=farmyard manure.
2. Mean of 18 years; HS=Highly significant.

soil fertility and plant nutrition management strategy. Flinn and De Datta (1984), Hobbs et al. (1993), and Regmi (1994) also reported yield decline with full recommended dose of fertilizer. Nambiar and Abrol (1989) found a declining trend even with NPK in many fertility experiments in India.

Both NPK and NP treatments showed declining trend; however, NP was slightly inferior to NPK indicating K was also limiting grain yield of early rice. Combined analysis also clearly showed that NPK was significantly superior to NP. Response of K was clearly seen in normal rice from the start of the experiment (Fig. 2) indicating that yield reduction in NP treatment was due to inadequate supply of soil K. Yield trends of different treatments were more or less similar in early and normal rice but degree of decline was slightly less in normal rice. Linear regression showed negative slope in early rice in all nine treatments (Table 6). Maximum yield loss per year was found in minus P treatments. Low dose of NP with straw (T8) showed minimum yield loss. In normal rice, all treatments except NPK (T5) and FYM (T9) have also shown negative slopes (Table 7). The maximum yield loss was however found in minus P treatments. Thus, P was found to be the major element to limit yield in both rice crops.

**Table 6. Regression for grain yield by year in early rice.**[1]

| Treatment | Fertilizer (kg ha$^{-1}$) | | | Crop | Intercept | Slope | R2 | Yield loss (% yr$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | N | P | K | | | | | |
| T1 | 0 | 0 | 0 | R&W | 1448 | –105.8 | 0.602 | –7.3 |
| T2 | 100 | 0 | 0 | R&W | 2687 | –198.8 | 0.559 | –7.4 |
| T3 | 100 | 13 | 0 | R | 3343 | –71.0 | 0.133 | –2.1 |
| | 100 | 17 | 0 | W | | | | |
| T4 | 100 | 0 | 25 | R&W | 2472 | –186.5 | 0.518 | –7.5 |
| T5 | 100 | 13 | 25 | R | 3692 | –87.8 | 0.224 | –2.4 |
| | 100 | 17 | 25 | W | | | | |
| T6 | 100 | 0 | 0 | R | 3267 | –115.0 | 0.371 | –3.5 |
| | 100 | 17 | 25 | W | | | | |
| T7 | 50 (+30 cm stubble) | 0 | 0 | R&W | 2100 | –156.0 | 0.579 | –7.4 |
| T8 | 50 (+30 cm stubble) | 9 | 0 | R&W | 2489 | –43.8 | 0.066 | –1.8 |
| T9 | 0 (FYM 10 t ha$^{-1}$) | 0 | 0 | R&W | 3524 | –65.7 | 0.165 | –1.9 |

1. NPK=nitrogen, phosphorus, potassium; FYM=farmyard manure; R=rice; W=wheat.

**Table 7. Regression for grain yield by year in normal rice.**[1]

| Treatment | Fertilizer (kg ha$^{-1}$) | | | Crop | Intercept | Slope | R2 | Yield loss (% yr$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | N | P | K | | | | | |
| T1 | 0 | 0 | 0 | R&W | 1992 | –90.9 | 0.387 | –4.6 |
| T2 | 100 | 0 | 0 | R&W | 2597 | –121.9 | 0.306 | –4.7 |
| T3 | 100 | 13 | 0 | R | 2574 | –5.8 | 0.002 | 0.2 |
| | 100 | 17 | 0 | W | | | | |
| T4 | 100 | 0 | 25 | R&W | 2731 | –145.9 | 0.404 | –5.2 |
| T5 | 100 | 13 | 25 | R | 3050 | 9.9 | 0.006 | 0.3 |
| | 100 | 17 | 25 | W | | | | |
| T6 | 100 | 0 | 0 | R | 2627 | –50.7 | 0.088 | –1.9 |
| | 100 | 17 | 25 | W | | | | |
| T7 | 50 (+30 cm stubble) | 0 | 0 | R&W | 2335 | –117.3 | 0.375 | –5.0 |
| T8 | 50 (+30 cm stubble) | 9 | 0 | R&W | 2634 | –5.4 | 0.002 | –0.2 |
| T9 | 0 (FYM 10 t ha$^{-1}$) | 0 | 0 | R&W | 3117 | 126.0 | 0.005 | 0.4 |

1. NPK=nitrogen, phosphorus, potassium; FYM=farmyard manure; R=rice; W=wheat.

Significant residual effect of P applied in wheat was found in both rice crops (Figs. 3 and 4; Table 5). This indicates that additional P applied to wheat could be utilized by succeeding rice crops. Regmi (1994) worked with the same set of trial and reported significant residual effect of P applied to wheat on the succeeding rice crops. Generally 15–20% of applied P is utilized by lowland rice, and rest is slowly available to succeeding crops (Kolar and Grewal 1988). Regmi (1994) also noted that P applied to wheat significantly increased grain yield of succeeding crops.

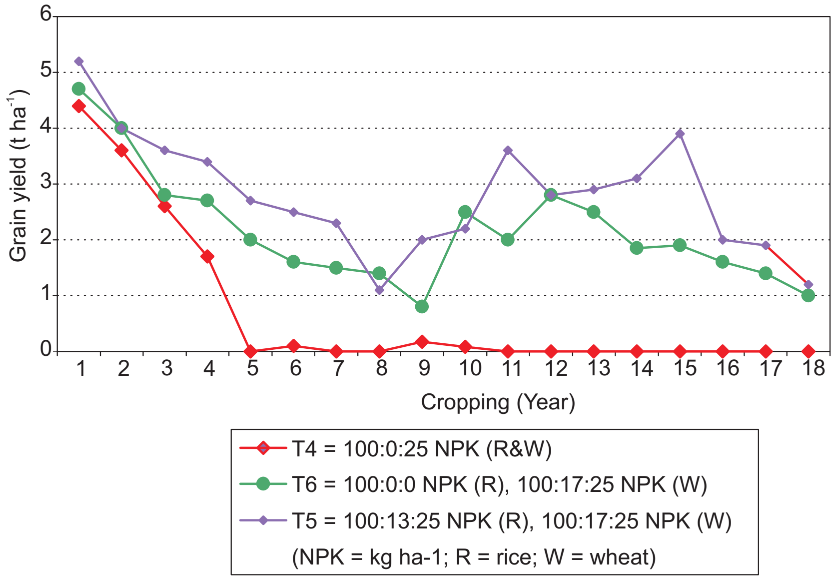


**Figure 3. Residual effect of long-term application of phosphorus (P) on early rice at Bhairawaha, Nepal.**

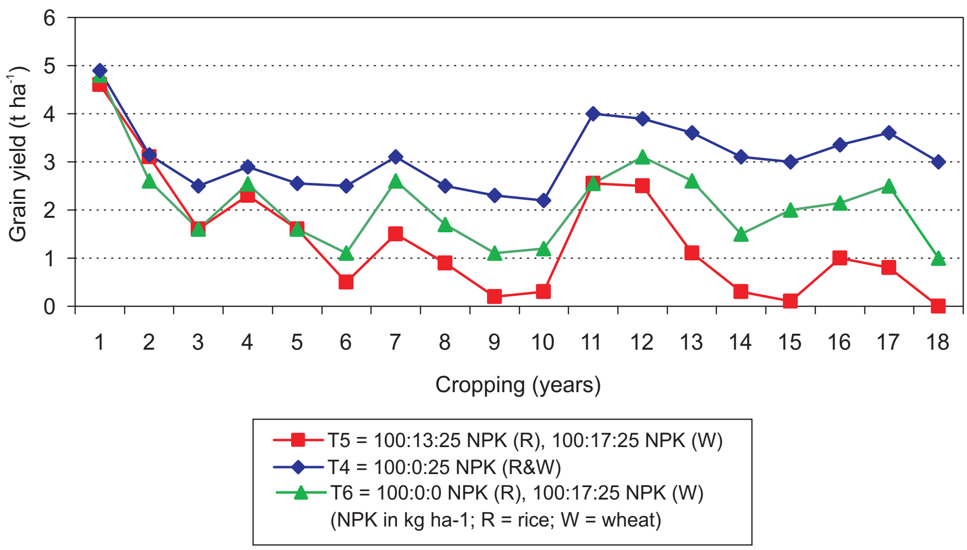


**Figure 4. Residual effect of long-term application of phosphorus (P) on normal rice at Bhairawaha, Nepal.**

Significant yield differences were found in treatments with 50–100 kg N ha$^{-1}$ which indicates that 50 kg N ha$^{-1}$ could not meet crop requirement (Fig. 5; Table 5). General yield increase in all the treatments in the 11th year could be due to the replacement with the high-yielding variety Janaki (Table 3). The varietal differences in plant nutrients uptake including P were reported by IRRI (1970) and Fageria et al. (1988).

### Yield trends of wheat

Response of wheat crop to full dose of fertilizer (T5, 100:13:25-R, 100:17:25-W) was different than rice crops. Unlike rice crops, no grain yield decline was observed in wheat with full dose of NPK until the 16th year. The yield, rather, increased or sustained in most of the years (Fig. 6). However, similar to rice, yields in all the treatments with minus P have declined close to zero. Significant yield differences were observed between NPK and NP treatments in wheat also, indicating response of K application. Soil exchangeable K was below critical level of 2.0 meq kg$^{-1}$ soil in all the treatments including FYM (Table 8).

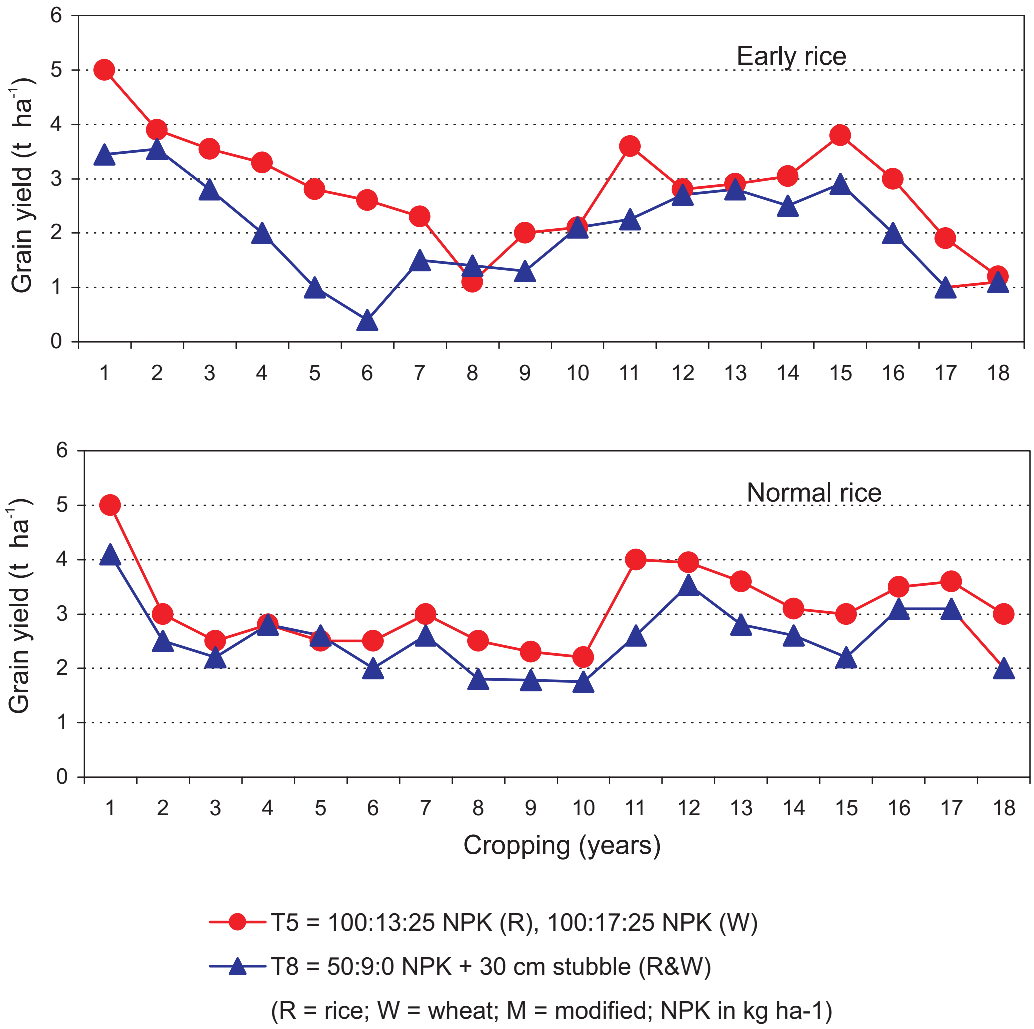


**Figure 5. Effect of different levels of nitrogen (N) on the yield of early and normal rice at Bhairawaha, Nepal.**

**Table 8. Effects of 13 years of cropping on soil chemical properties.**[1]

| Treatment[2] | pH (1:1 $H_2O$) | Organic carbon | Total N (%) | Total P ($\mu g\ g^{-1}$) | CEC (meq $100g^{-1}$) | Exchangeable mineral (meq $100g^{-1}$) | | | | Available mineral ($\mu g\ g^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | K | Ca | Mg | Na | P | B | Zn |
| T1 | 8.1 b | 0.73 a | 0.05 a | 140 f | 10.5 a | 0.05 b | 26.8 a | 6.85 a | 0.19 a | 2.5 a | 0.17 a | 0.02 a |
| T2 | 8.1 b | 0.73 a | 0.08 a | 158 ef | 10.2 a | 0.03 a | 20.3 a | 5.75 a | 0.27 ab | 2.1 c | 0.17 a | 0.04 a |
| T3 | 8.1 b | 0.90 c | 0.10 e | 230 b | 11.1 a | 0.04 ab | 25.3 a | 6.30 a | 0.26 b | 4.9 b | 0.25 a | 0.03 a |
| T4 | 8.1 b | 0.77 ab | 0.08 ab | 143 f | 11.0 a | 0.08 c | 20.6 a | 6.02 | 0.17 a | 3.0 bc | 0.26 a | 0.04 a |
| T5 | 8.1 b | 0.88 c | 0.10 de | 204 c | 10.9 a | 0.03 a | 21.5 a | 6.02 a | 0.26 b | 4.3 bc | 0.24 a | 0.03 a |
| T6 | 8.1 b | 0.85 bc | 0.09 cd | 169 de | 11.0 a | 0.05 a | 22.7 a | 5.75 a | 0.23 ab | 2.7 bc | 0.35 a | 0.03 a |
| T7 | 8.1 b | 0.75 ab | 0.09 bc | 145 f | 10.1 a | 0.05 a | 18.1 a | 6.03 a | 0.17 a | 2.3 c | 0.23 a | 0.03 a |
| T8 | 8.1 b | 0.88 c | 0.09 cd | 186 cd | 11.4 a | 0.05 a | 23.6 a | 6.30 a | 0.23 ab | 3.7 bc | 0.24 a | 0.03 a |
| T9 | 7.9 a | 1.75 d | 0.17 f | 293 a | 15.8 b | 0.05 a | 27.8 a | 10.4 | 0.28 b | 14.4 d | 0.32 a | 0.04 a |
| Initial | 8 | 1.03 | 0.09 | | | 0.32 | | | | 9.8 | | |

1. In a column, means with the same letters are not significantly different at 5% level by DMRT.
   N=nitrogen; P=phosphorus; CEC=cation exchange capacity; K=potassium; Ca=calcium; Mg=magnesium; Na=sodium; B=boron; Zn=zinc.
2. See Table 1 for treatments.

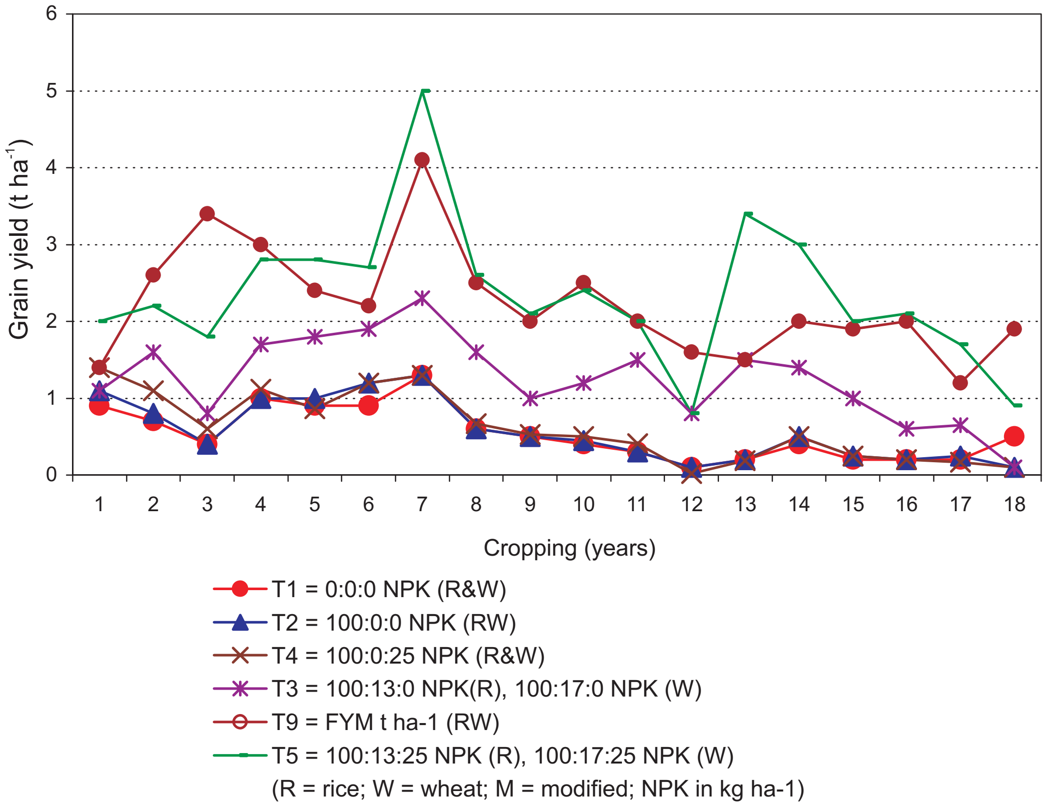


**Figure 6. Effect of long-term fertilization on the yield of wheat at Bhairawaha, Nepal.**

The FYM and NPK treatments showed similar yield trends. General yield increase in the 7th year is difficult to explain; however, timely sowing and change in variety (Table 4) might have contributed to some extent. Low yield in all treatments in 12th year was probably due to late planting (Dec 22). High dose of N (T5) produced significantly higher grain yield (Fig. 7) than low dose (T8) which clearly show that 50 kg N $ha^{-1}$ could not meet the crop demand. However, in 12th year both doses produced similar yield, indicating that

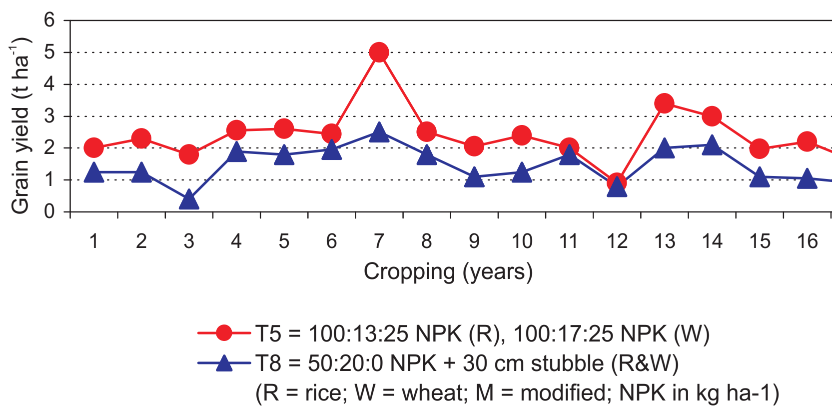


**Figure 7. Effect of different levels of nitrogen (N) on the yield of wheat at Bhairawaha, Nepal.**

**Table 9. Regression for grain yield by year in wheat.**[1]

| Treatment | Fertilizer (kg $ha^{-1}$) | | | Crop | Intercept | Slope | $R^2$ | Yield loss |
|---|---|---|---|---|---|---|---|---|
| | N | P | K | | | | | (% $yr^{-1}$) |
| T1 | 0 | 0 | 0 | R&W | 993 | –44.8 | 0.475 | –4.5 |
| T2 | 100 | 0 | 0 | R&W | 1133 | –55.1 | 0.585 | –4.9 |
| T3 | 100 | 13 | 0 | R | 1813 | –60.7 | 0.361 | –3.3 |
| | 100 | 17 | 0 | W | | | | |
| T4 | 100 | 0 | 25 | R&W | 1293 | –68.9 | 0.701 | –5.3 |
| T5 | 100 | 13 | 25 | R | 2746 | –43.7 | 0.067 | –1.6 |
| | 100 | 17 | 25 | W | | | | |
| T6 | 100 | 0 | 0 | R | 2461 | –47.0 | 0.106 | –1.9 |
| | 100 | 17 | 25 | W | | | | |
| T7 | 50 (+30 cm stubble) | 0 | 0 | R&W | 1076 | –57.4 | 0.651 | –5.3 |
| T8 | 50 (+30 cm stubble) | 9 | 0 | R&W | 1723 | –31.1 | 0.091 | –1.8 |
| T9 | 0 (FYM 10 t $ha^{-1}$) | 0 | 0 | R&W | 2821 | –64.2 | 0.201 | –2.3 |

1. NPK=nitrogen, phosphorus, potassium; FYM=farmyard manure; R=rice; W=wheat.

in late planting 100 kg N $ha^{-1}$ was not fully utilized by the crop and thus high dose may not be economical in late-planting condition. Yield loss $yr^{-1}$ was maximum (7.5%) in minus P treatments and minimum in NPK and low dose of NP with 30 cm stubble (Table 9).

### Effect of modifications in fertilizer application

Application of Zn in early rice in 1990 did not significantly affect grain yield of rice and wheat (data not shown). In 1991, replenishment of P and K [modified (M) treatment] (T2M) boosted up grain yields of both the rice crops and showed a similar trend as NPK treatment (T5) in most of the years (Figs. 8 and 9) as compared to zero/low yield in early and normal rice (T2). In wheat also the modified treatment (T2M) produced similar yield as NPK treatment (T5) (Fig. 10).

Addition of 50 kg N $ha^{-1}$ to FYM treatment (T9M) produced more yields than T9. However, the yield gap widened significantly from 1995 onwards, when 42 kg K $ha^{-1}$ was added in addition to 50 kg N $ha^{-1}$. This indicates that response of N was not pronounced because of limitation of K (Fig. 11). In wheat, addition of 50 kg N $ha^{-1}$ to FYM treatment (T9M) boosted yield in the 1st year of application and thereafter, produced yields similar to FYM (T9). However, from 1995 onwards the yield in modified T9 (T9M) was significantly higher than that in T9 and T9M (1991–94) when 50 kg N $ha^{-1}$ was applied with 42 kg K $ha^{-1}$ (Fig. 12).

From 1995 onwards, application of NPK (100:22:83) to control (no fertilizers) treatment produced grain yields higher than NPK (T5) treatment in both rice crops (Fig. 13) while

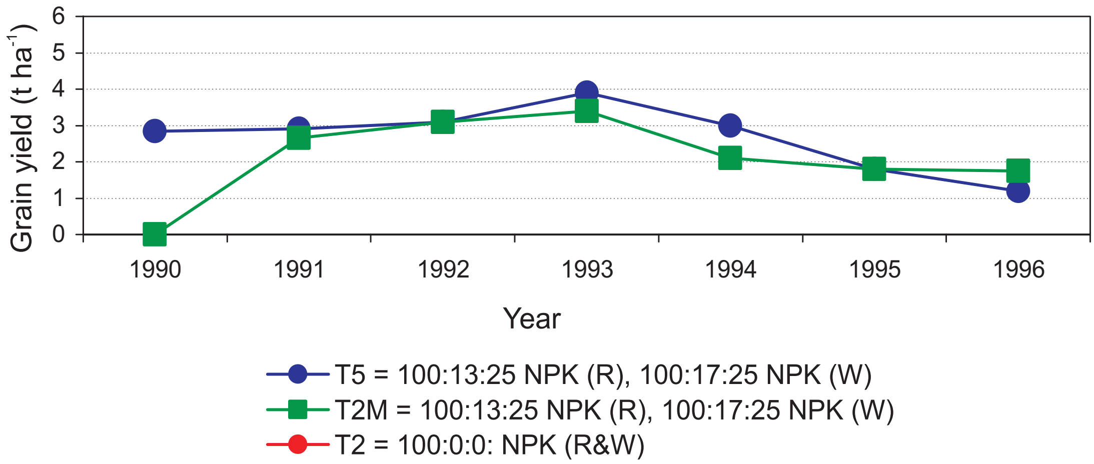


**Figure 8. Effect of increase in phosphorus (P) and potassium (K) inputs on the yield of early rice at Bhairawaha, Nepal during 1990–96.**

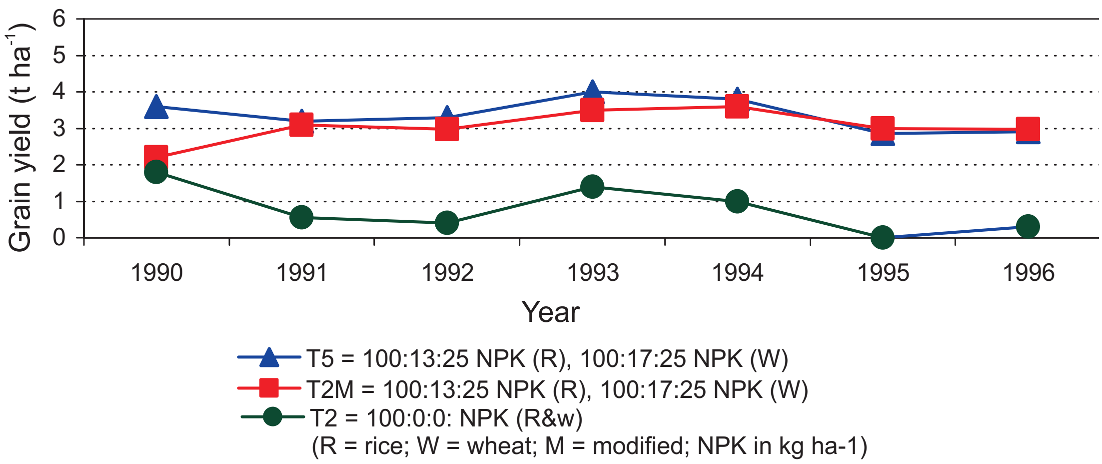


**Figure 9. Effect of increase in phosphorus (P) and potassium (K) inputs on the yield of normal rice at Bhairawaha, Nepal during 1990–96.**

the yield in original control treatments were very low in normal rice and zero in early rice. In 1995, wheat yield in modified control treatment (T1M) was almost double that in NPK (T5) treatment. However, in 1996, both T1M and T5 produced similar yields (Fig. 13). In Terai, generally western hot wind causes forced maturity of wheat, which is one of the main causes of low yield. However, 1996 was one of the exceptional years when hot winds did not come at post anthesis period, and overall wheat yields were high.

Both the rice crops resonded better with application of K in T3M than T5M (Fig. 14). This indicates that depletion of K could have been more in T3 than in T5 that receives regular K dressing. Similar trend was observed in wheat (Fig. 14). However, response of K was higher in wheat than in rice crops. Effect of replenishment of K was pronounced in 1995 compared to 1996. However, higher yields were obtained in original (T3 and T5) and modified treatments (T3M and T5M) in 1996 due to favorable weather. Eastern hot wind (heat

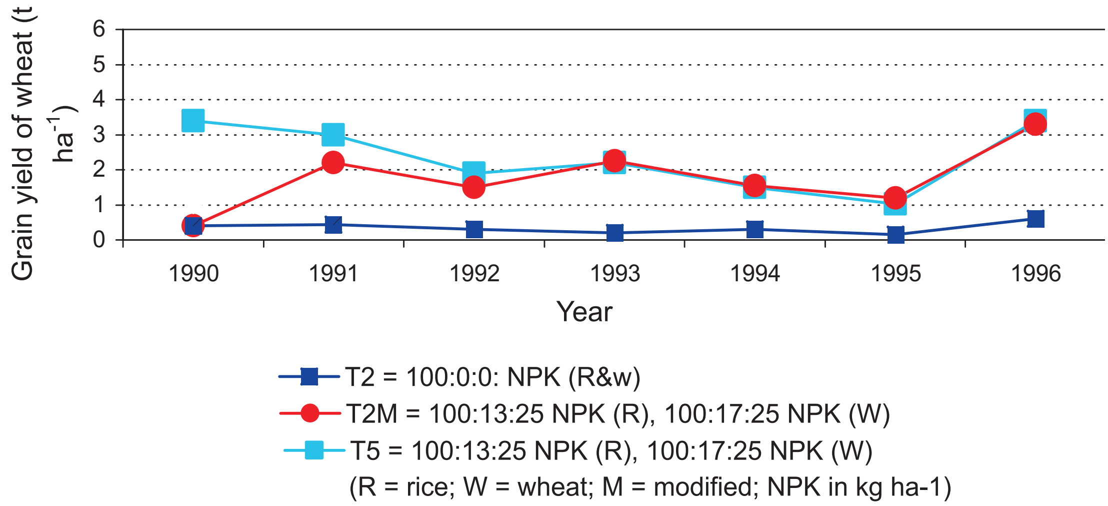


Figure 10. Effect of increase in phosphorus (P) and potassium (K) inputs on the yield of wheat at Bhairawaha, Nepal during 1990-96.

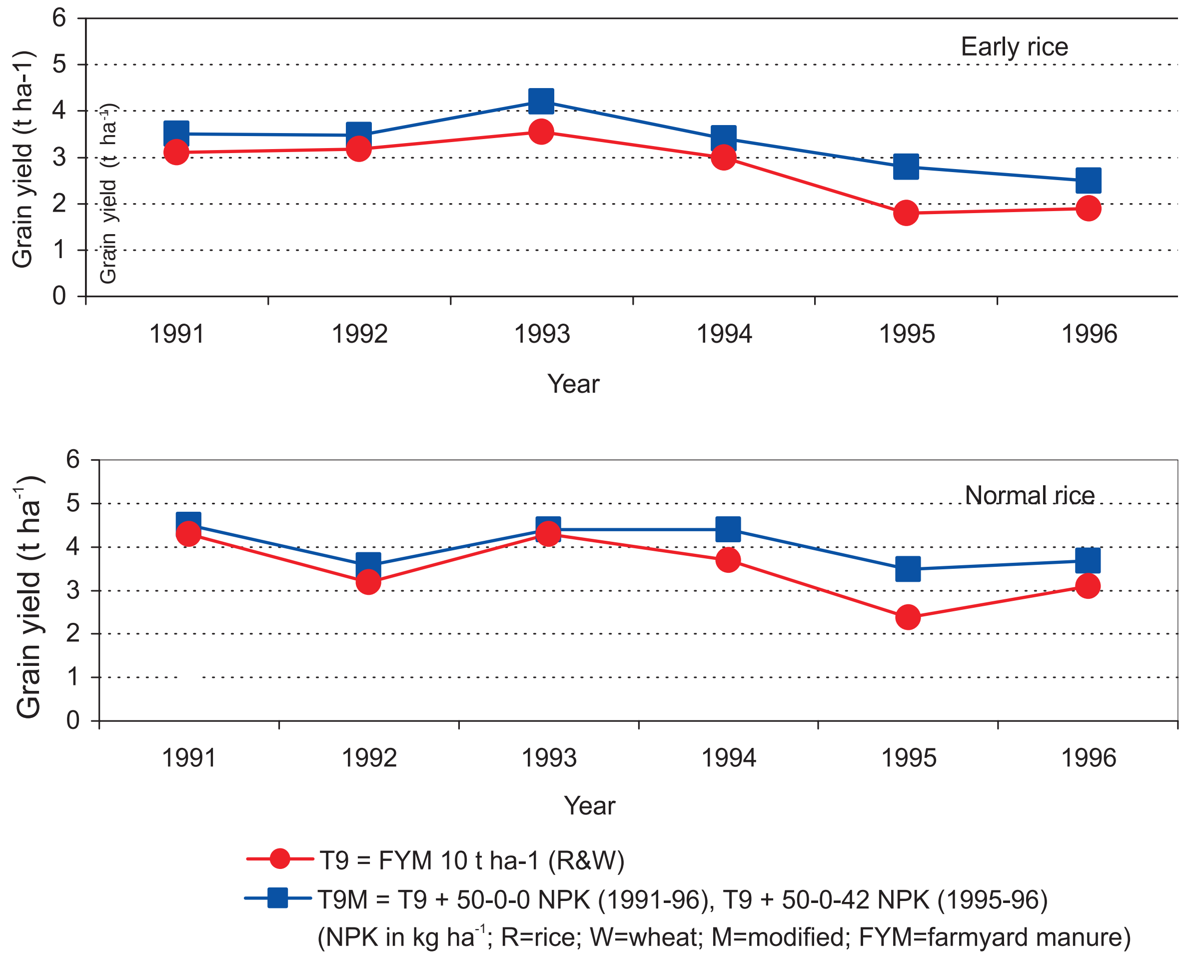


Figure 11. Effect of increase in nitrogen (N) and potassium (K) inputs on the yield of early and normal rice at Bhairawaha, Nepal during 1991–96.

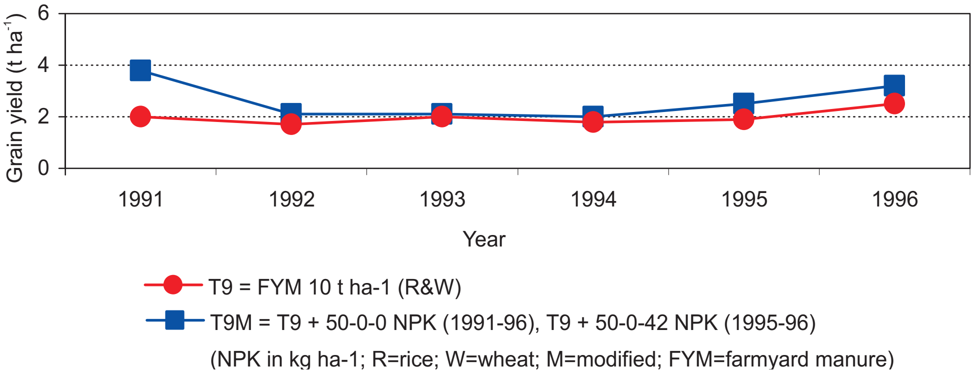


**Figure 12. Effect of increase in nitrogen (N) and potassium (k) inputs on the yield of wheat at Bhairawah, Nepal during 1991–96.**

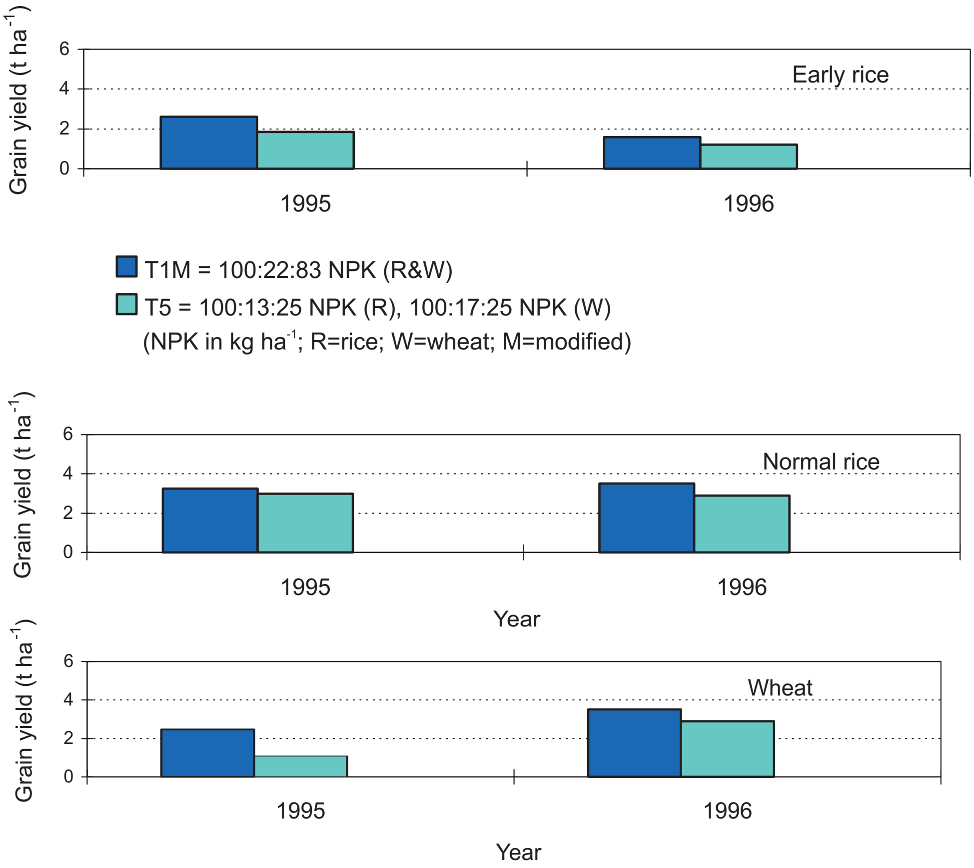


**Figure 13. Effect of fertilizer application to control plots on crop yields at Bhairawaha, Nepal during 1995–96.**

stress) causes shriveled grain resulting in low yield. Since one of the major roles of K is to make plumpy grain (Yawalkar et al. 1977), it is likely that addition of K might have reduced yield loss in heat stress condition in 1995. The initial status of K dropped from 3.2 to 0.3 meq $kg^{-1}$ soil in NPK treatment (Table 5). This proves that yield reduction was also due to K deficiency.

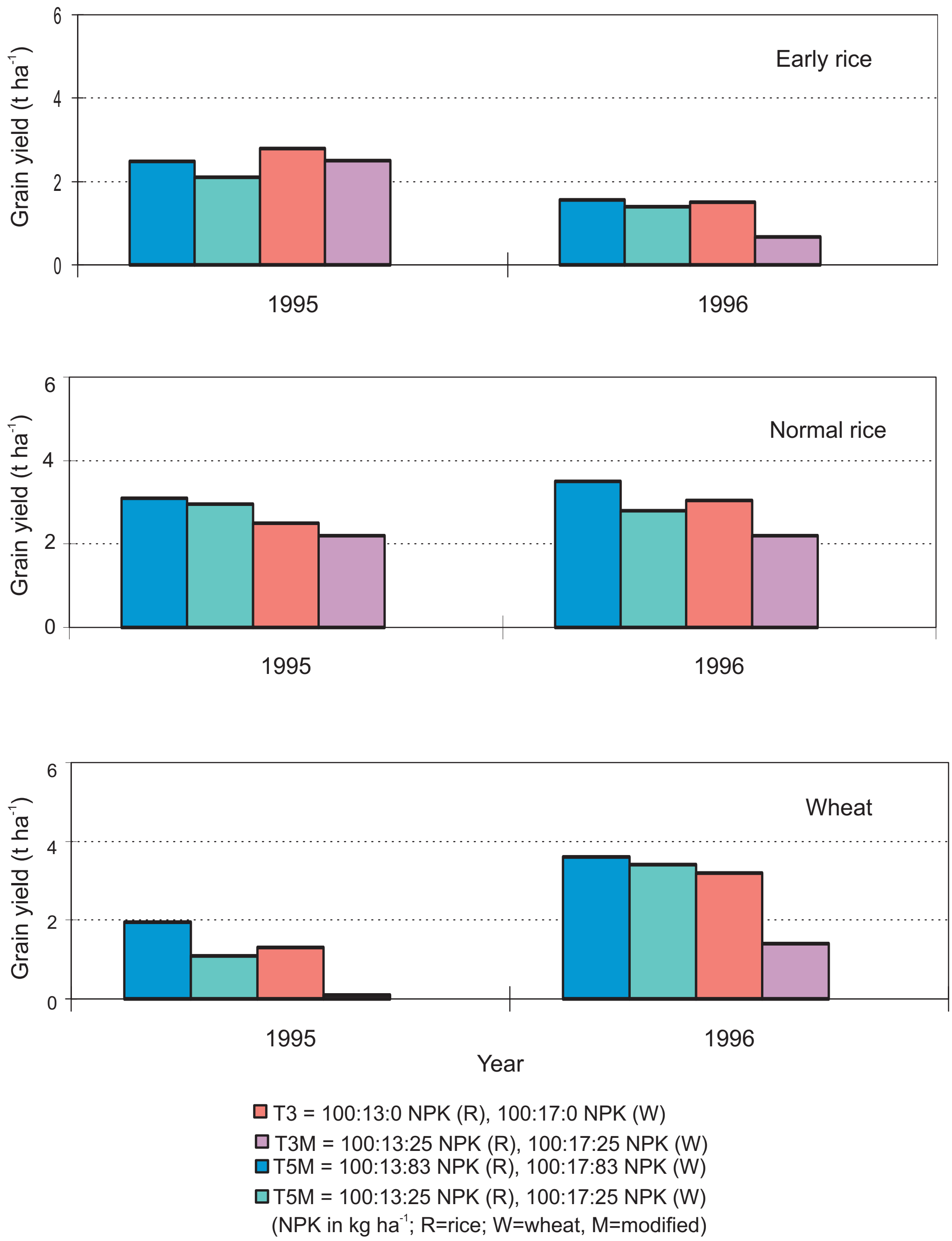


**Figure 14. Effect of increase in potassium (K) inputs on crop yields at Bhairawaha, Nepal during 1995–96.**

### Yield trends of the cropping system

Both NPK (T5) and FYM (T9) could not sustain yields. Linear regression showed that the annual yield decline was 121 kg $ha^{-1}$ in NPK treatment and 117 kg $ha^{-1}$ in FYM treatment. On the basis of cluster analysis of all the 3 crops (early rice, normal rice, and wheat), two main clusters, i.e., plus P and minus P treatments were distinctly observed.

### Effect of long-term fertilization on soil properties

No significant change in initial pH was observed due to continuous application of fertilizers or FYM. Application of 10 t FYM $ha^{-1}$ (T9) increased organic carbon content of the soil from 1.03% to 1.75%, while in other treatments it decreased. Total N increased by the continuous application of FYM from 0.09% to 0.17%. Lowest N (0.05%) was found in control treatment which was lower than initial soil test N. It increased available (Olsen) P over initial level of 9.8 mg P $kg^{-1}$ soil (Table 5). In other treatments available P was below the initial level. Continuous application of P increased total P compared to non-P receiving treatments. FYM contributed more to total P than P-treated plots. Exchangeable K was below the initial level in all the treatments, indicating that K removal was not commensurate to input of 75 kg K $ha^{-1}$ $yr^{-1}$ or 30 t FYM $ha^{-1}$ $yr^{-1}$.

## Conclusion

The yield trend is mainly controlled by P fertilization, followed by K. In the long run, crop yields can only be sustained if N, P, and K supplies are adequately balanced to replenish crop removals. Application of FYM at 10 t $ha^{-1}$ to each crop can also produce yields equivalent to 100:17:25 kg NPK $ha^{-1}$. Additionally, it improves soil fertility. The present rates of fertilizer at 100:13:25 kg NPK $ha^{-1}$ or FYM at 10 t $ha^{-1}$ for each of the crops in rice-rice-wheat pattern are insufficient to sustain increased yields on long-term basis. Yield trends can be reversed if P and K are supplied along with N in depleted soils.

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