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**Review/Overview**

# Long-term effect of integrated nutrient management in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system

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## ABSTRACT

A field experiment was conducted on permanent manurial trial, initiated during the rainy (*kharif*) season 1985 at JNKVV, Jabalpur, to evaluate the long-term impact of fertilizer and manure and their integration on yield trends, production efficiency and soil-quality parameters and their inter-relationship with sustainable yield index (SYI) under rice (*Oryza sativa* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] cropping sequence. The treatment 50% NPK + 50% N substituted through farmyard manure (FYM) to rice and 100% NPK to wheat provided the highest wheat-equivalent yield (WEY 8.01 t/ha) with net monetary returns (₹42.7 × $10^3$/ha) and recorded 430% higher system productivity over the control. The next best treatment was 50% NPK + 50% N substituted through green leaf manure (GLM) of sunhemp (*Sesbania aculeata* L.) to rice and 100% NPK to wheat gave higher WEY of 7.97 t/ha with net monetary returns (42.1 × $10^3$/ha). The treatment 50% NPK + 50% N substituted through farm yard manure (FYM) to rice and 100% NPK to wheat and 50% NPK + 50% N substituted through GLM to rice and 100% NPK to wheat also increased organic carbon (7.6 g and 7.9 g/kg), available N (282 and 292 kg/ha), $P_2O_5$ (15.4 and 17.2 kg/ha), $K_2O$ (466 and 488 kg/ha), S (8.4 and 8.5 kg/ha) and Zn (0.43 and 0.45 kg/ha), sustained soil pH (7.49 and 7.48) and electrical conductivity (EC) (0.58 and 0.63 dS/m) and lowered the bulk density (1.27 and 1.27 g/cm$^3$). In the treatment receiving 100–100% NPK through fertilizer to both rice and wheat crops, the total productivity was higher (7.72 t/ha). The higher sustainable yield index (0.83) was observed with 50% NPK + 50% N substituted through GLM to rice and 100% NPK through fertilizer to wheat crop. Maximum beneficial micro-organisms, viz. fungi, bacteria, azotobacter, phosphorus solubilizing bacteria and actinomycetes were recorded with the integrated nutrient practices. Negative trend of net monetary returns was noted with control plot.

***Key words*** **:** Integrated nutrient management, Long-term study, Rice–wheat cropping sequence, Soil quality.

In India, rice–wheat cropping system is an existing cropping system across the Indo-Gangetic plains and in the Himalayan foothills. Approximately 9.85 m ha area is under this cropping system and contributes 25% of total foodgrain in India. Both these crops are grown year after year in the same field. Current generalized recommendations with respect to NPK fertilizers alone are pointing to soil degradation, proving their declined efficiency and thus needing improvement through proper nutrition. The concept of balanced fertilization includes application of all essential nutrients for higher productivity and health of soil. Imbalanced fertilization of plant nutrients resulted in the emergence of deficiencies of phosphorus, potassium, sulphur, zinc, iron, boron, manganese and copper in the soils and plants on a large scale.

The integrated nutrient supply system is the most logical concept for managing long-term soil fertility and productivity (Ramesh *et al.*, 2009). Use of chemical fertilizers and organic manures has been found promising in arresting the decline trend in soil-health and productivity through the correction of marginal deficiencies of some secondary and micro-nutrients, micro-flora and fauna and their beneficial influence on physical and biological properties of soil. Integrated nutrient management system can bring about equilibrium between degenerative and restorative activities in the soil eco-system (Upadhyay *et al.*, 2011). Hence, a long-term nutrient-management experiment has been conducted since 1985-86 to till date at Breeder Seed Production unit (BSP), Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, to evaluate and understand the factors that influence the soil health and crop productivity.

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## MATERIALS AND METHODS

A field experiment was conducted during 1985–86 to 2010–11 (still continue) on *'Vertisol'* of breeder seed production (BSP) unit of JNKVV, Jabalpur (23° 90' N and 70° 90' E with an altitude of 411.78 m above the mean sea-level), Madhya Pradesh. It enjoys the feature of subtropical and semi-arid climate.

Generally, rains receive in Kymore plateau region through south–west monsoon and starts during the second to third week of June and it terminates by the first week of October. The rains are mainly concentrated during July–August with uneven distribution associated with long dry spells. There are an occasional and little (≤ 100 mm) showers in remaining winter and summer seasons. Total annual rainfall ranges between 1,100 and 1,500 mm. The maximum temperature rises extremely high up to 45°C during May–June, while minimum temperature goes down to a limit of 2°C during December–January.

The soil was neutral (pH 7.62) and normal in electrical conductivity (EC) (0.55 dS/m) with medium organic carbon (6.5 g/kg), available N (240 kg/ha), available P (16 kg/ha) and high in available K (448 kg/ha) contents. Total 12 treatments comprising 4 treatments of inorganic sources, viz. 50–50% of recommended NPK to rice and wheat; 50% NPK to rice and 100% NPK to wheat; 75–75% NPK to rice and wheat; and 100–100% NPK to rice and wheat, of different levels of recommended fertilizers, 6 of integration of organic and inorganic sources viz.; 50% NPK + 50% N through FYM to rice and 100% NPK to wheat; 75% NPK + 25% N through FYM to rice and 75% NPK to wheat; 50% NPK + 50% N through wheat straw (WS) to rice and 100% NPK to wheat; 75% NPK + 25% N through WS to rice and 75% NPK to wheat; 50% NPK + 50% N through GLM to rice and 100% NPK to wheat; 75% NPK + 25% N through Green leaf manure (GLM) to rice and 75% NPK to wheat along with no-application of nutrients (control) and farmer's practices of manuring (40 kg N + 20 kg $P_2O_5$ + 3 tonnes FYM/ha to rice followed by 40 kg N + 20 kg $P_2O_5$ to wheat) were imposed. Different organic manures, viz. FYM (0.5, 0.25 and 0.5% NPK), WS (0.36, 0.08 and 0.93% NPK) and GLM of sunnhemp (1.35, 0.49 and 1.2% NPK) were analysed and their quantities, required to substitute a specified amount of N (50 and 25%) as per the treatments were calculated. Recommended NPK for both the crops were 120 kg N, 26.4 kg $P_2O_5$ and 33.3 kg $K_2O$/ha. These were applied as per the treatment through urea, single superphosphate and muriate of potash respectively. The yield was recorded for 1990–91 to 2010–11 and was pooled. The experiment was laid out in a randomized block design with 4 replications.

During the years, rice 'Kranti' was grown by using 40 kg seeds/ha under transplanting with 20 cm × 15cm planting geometry and the succeeding wheat 'Lok 1' and 'GW 273' was grown by using 100 kg seeds/ha in rows 20 cm apart. The crops were grown under assured irrigation as per need of crop. Other cultural practices, viz. weed management and plant-protection measures, were followed as per local recommendation. Data on grain yield of individual crop were recorded and then combined yield, of entire cropping system was determined as wheat-equivalent yield and production efficiency with the help of existing market price of rice and wheat grains.

Sustainable yield index (SYI) is the ratio of minimum assured seed yield to maximum observed yield was calculated as per Singh *et al.*, (1990)

$$SYI = (Ya-\sigma)/Ym \quad ............... \quad (1)$$

Where Ya is mean yield, ó is the standard deviation of the yield and Ym is the maximum yield obtained under a set of management practices. The nearness of SYI to 1.00 implies the closeness to an ideal condition that can sustain maximum crop yield over the years, while deviation from 1.0 indicates the losses to sustainability (Bhindhu and Gaikwad, 1998).

Production efficiency (PE) represents the seed yield on a daily basis and calculated by dividing total rice seed production/ha in a sequence with total duration of the crops in a sequence (Tomar and Tiwari, 1990). Bulk density, pH, EC, organic carbon, available NPK, S and Zn were estimated as per standard procedures. The changes in soil parameters over their initial status after completion of 25 crop cycles under each treatment were determined.

## RESULTS AND DISCUSSION

### *Grain yield*

*Rice*: Application of 50% NPK + 50% N substituted through GLM to rice resulted in the maximum grain yield, which was 148% higher over the control followed by 50% NPK + 50% N substituted through FYM (135%). This improvement in seed yield was owing to incorporation of GLM and FYM, attributed to its ability to proper nutrient supply throughout the growing season (Table 1). The treatment receiving suboptimal dose of nutrients, i.e. 50 and 75% or even 100% without organic manures, though the yield was higher over the control, but these treatments showed declined yield and the sulphur and zinc deficiency. Continuous cropping without addition of organic manures or sulphur/zinc fertilizer (imbalanced fertilization) reduced the grain yield than treatment receiving balanced amount of nutrient through inorganic and organic sources. Thus the balanced application of mineral fertilizers sustains soil physical environment and higher crop productivity under intensive cultivation (Hati *et al.,* 2006).

*Wheat:* Treatment receiving 50% NPK + 50% N substituted through GLM (2.98t/ha) and FYM (2.85t/ha) enhanced the productivity of wheat by 282 and 259% respectively. Both these treatments were found superior to the treatments receiving 100% NPK through fertilizer and the control. Farmers' practice of raising wheat crop gave higher grain yield by 124% over the control. As the dose of chemical fertilizer increases the yield of crop correspondingly increases.

### Production efficiency

Higher production efficiency was recorded under the treatment receiving 50% NPK + 50% N substituted through *ex-situ* green leaf manuring of sunhemp to rice and 100% NPK to wheat followed by 50% NPK + 50% N substituted through FYM to rice and 100% NPK to wheat. All the other treatments receiving nutrients through chemical fertilizers showing decline trend regarding the production efficiency under continuous growing of rice–wheat cropping system. The application of GLM along with fertilizer was beneficial in enhancing the crop productivity and soil fertility and gave higher production efficiency of the system (Table 2).

### System productivity

As regards the system productivity in terms of wheat-equivalent yield (WEY), profitability played a key role in determining the most productive and profitable cropping sequence (treatments).The pooled analysis (1990–2010) of different treatments revealed that treatments 50% NPK + 50% N substituted through FYM to rice and 100% NPK to wheat gave the highest WEY, being 430% higher over the control followed by treatment that receiving 50% NPK + 50% N substituted through GLM to rice and 100% NPK to wheat and was 427% higher over the control. In this system, treatment received optimal dose of fertilizer (100–100%) to both rice and wheat resulted in higher WEY than 75–75%, 50–100% and 50–50% NPK to these crops and found 328, 305 and 247% respectively higher grain yields over the control (Priyadarshani *et al.,* 2012).

### Economics

The pooled data of 20 years (1990–2010) on economic aspect, are presented in Table 2, showed that cost of cultivation was higher for treatment receiving 50 or 25% N substituted through green leaf manuring or farmyard manure or wheat straw as compared to nutrient applied through inorganic fertilizer only. Growing of sunhemp and its *ex-situ* green leaf manuring and application of FYM and wheat straw for 50 or 25% N as per the treatments enhances the cost of cultivation.

There was variation in net returns and benefit: cost ratio (Table 2). Higher net returns were recorded under treatment 75% NPK + 25% N substituted through FYM to rice and 75% NPK to wheat ($42.8 \times 10^3$/ha) with benefit: cost ratio of 2.2 followed by 50% NPK + 50% N substituted through FYM to rice and 100% NPK to wheat ($42.78 \times 10^3$/ha) with benefit: cost ratio of 2.14 and 75% NPK + 25% N substituted through GLM to rice and 75% NPK to wheat ($38.98 \times 10^3$/ha) with benefit: cost ratio of 2.09. The impact was minimum, when application of wheat straw was done at any amount (50% or 25% N) to rice in rice–

**Table 1.** Mean grain yield (t/ha) of rice and wheat as affected by integrated nutrient management

| Treatment | | Mean yield (t/ha) of 5 years | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Kharif* (rainy season) | *Rabi* (winter season) | 1990–91 to 1994–1995 | | 1995–96 to 1999–2000 | | 2000–2001 to 2004– 2005 | | 2005–2006 to 2010–2011 | |
| | | Rice | Wheat | Rice | Wheat | Rice | Wheat | Rice | Wheat |
| Control | Control | 2.41 | 0.94 | 2.09 | 0.74 | 1.99 | 0.70 | 1.94 | 0.68 |
| 50% NPK | 50 % NPK | 3.99 | 1.72 | 3.26 | 1.66 | 4.02 | 1.60 | 3.93 | 1.60 |
| 50% NPK | 100 % NPK | 4.21 | 2.58 | 3.53 | 1.79 | 4.13 | 2.62 | 4.45 | 2.76 |
| 75% NPK | 75 % NPK | 4.84 | 2.19 | 4.08 | 1.87 | 4.71 | 2.38 | 5.02 | 2.80 |
| 100% NPK | 100 % NPK | 5.24 | 2.66 | 4.73 | 2.20 | 5.44 | 2.89 | 5.46 | 3.46 |
| 50% NPK + 50% N as FYM | 100 % NPK | 5.09 | 2.80 | 4.69 | 2.27 | 5.57 | 2.99 | 5.86 | 3.34 |
| 75% NPK + 25% N as FYM | 75 % NPK | 5.18 | 2.33 | 4.63 | 2.08 | 5.27 | 2.82 | 5.23 | 3.31 |
| 50% NPK + 50% N as WS | 100 % NPK | 4.80 | 2.70 | 4.30 | 2.06 | 5.23 | 2.93 | 5.26 | 3.44 |
| 75% NPK + 25% N as WS | 75 % NPK | 4.94 | 2.17 | 4.23 | 1.97 | 4.99 | 2.67 | 4.97 | 3.18 |
| 50% NPK + 50% N as GLM | 100 % NPK | 5.67 | 2.91 | 4.85 | 2.34 | 5.83 | 2.06 | 5.99 | 3.63 |
| 75% NPK + 25% N as GLM | 75 % NPK | 5.33 | 2.38 | 4.70 | 2.06 | 5.35 | 2.89 | 5.19 | 3.27 |
| FP ($N_{40}P_{20}$ + 3 t FYM/ha) | FP ($N_{40}P_{20}$ /ha) | 3.68 | 1.77 | 2.90 | 1.51 | 3.47 | 1.73 | 3.93 | 1.98 |
| | SEm± | 0.18 | 0.13 | 0.12 | 0.07 | 0.08 | 0.04 | 0.12 | 0.04 |
| | CD (P=0.05 ) | 0.56 | 0.43 | 0.35 | 0.23 | 0.23 | 0.13 | 0.34 | 0.14 |

*Kharif*, Rainy season; *Rabi*, Winter season; FYM, Farmyard manure; WS, Wheat straw; GLM, Green leaf manure; FP, Farmers practice wheat cropping system. Treatment receiving FYM, GLM and wheat straw in combination with fertilizers having lower benefit: cost ratio which lead to use of higher quantity of organic manure before sowing of *kharif* crop that raised cost of cultivation (Ramesh *et al.,* 2009) compared to treatment received chemical fertilizers (100-100% to rice and wheat).

### *Sustainable yield index (SYI)*

After completion of 25 years crop cycle (still in progress) the organic treatments (50% NPK + 50% N through FYM to rice and 100% NPK to wheat; 75% NPK + 25% N through FYM to rice and 75% NPK to wheat; 50% NPK + 50% N through WS to rice and 100% NPK to wheat; 75% NPK + 25% N through WS to rice and 75% NPK to wheat; 50% NPK + 50% N through GLM to rice and 100% NPK to wheat; 75% NPK + 25% N through GLM to rice and 75% NPK to wheat and farmers practices) along with fertilizer influenced the SYI (Table 2). *Sesbania* (GLM) increased the SYI by 82.7%, FYM by 78.7% and wheat straw by 68.7% over the control. Farmers practice of nutrient management was also recorded higher SYI by 41.7%. Similarly, successive improvement in fertilizer level increased the SYI over the control (no fertilizer, no manure). Premi *et al.,* (2012) also reported the similar findings.

### *Physical properties of soil*

After completion of 25 crop cycle, the treatment receiving nutrient through chemical fertilizer, the pH of these treatments were slightly higher than initial value (7.62). The increase in pH of soil profile attributes to continuous application of imbalance use of nutrient which decline soil health and increase soil pH. Soil pH of 7.48 and 7.49 (Table 3) recorded the lowest under 50% NPK + 50% N substituted through GLM and FYM, respectively, to rice and 100% NPK to wheat over initial value. Decrease in soil pH may be attributed to balance use of fertilizer with GLM and FYM, which released the organic acid during decomposition of manures resulting declining in soil pH (Priyadarshani *et al.,* 2012). Electrical conductivity (EC) was not much affected due to different fertility treatments over their initial value (0.55). The highest EC (0.63 dS/m) was found under treatment 50% NPK + 50% N substituted through GLM to rice and 100% NPK to wheat. There was slightly increase in EC (Table 3) where balanced nutrition applied to both crops. This increase in EC obviously was due to decomposition of organic matter. These results corroborate the findings of Babu *et al.,* (2007).

After continuous cropping of rice (transplanted) and wheat crops, the bulk density was slightly higher where no fertilizer and no manures were applied (control) and also under imbalanced use of fertilizer. But substitution of either 50 or 25% N through GLM, FYM and WS along with NPK fertilizer, lowered the bulk density (1.27g/cm) which provided congenial environment for aeration, root proliferation and plant development. These results corroborate the findings of Singh *et al.* (2009).

The addition of organic matter (FYM, GLM and WS) with chemical fertilizer over 25 years, resulted in increase

**Table 2.** Productivity and net monetary returns (NMR) in rice-wheat sequence under varying nutrient management

| Treatment *Kharif* (rainy season) | *Rabi* (winter season) | Mean yield of 20 years (t/ha) Rice | Wheat | WEY (t/ha) | SYI | Production efficiency (kg/ha/day) | NMR (×10$^3$ ₹/ha) | Benefit: cost Ratio |
|---|---|---|---|---|---|---|---|---|
| Control (no fertilizer, no manure) | Control | 2.25 | 0.78 | 1.51 | 0.27 | 5.9 | -11.3 | 0.61 |
| 50% NPK | 50 % NPK | 3.80 (68.8)* | 1.97 (153) | 5.24 (247%) | 0.48 | 18.2 | 22.8 | 1.71 |
| 50% NPK | 100 % NPK | 4.08 (81.3) | 2.43 (211) | 6.13 (305%) | 0.56 | 21.1 | 29.9 | 1.89 |
| 75% NPK | 75 % NPK | 4.66 (107.1) | 2.31 (196) | 6.47 (328%) | 0.60 | 23.0 | 35.7 | 2.06 |
| 100% NPK | 100 % NPK | 5.22 (132) | 2.80 (259) | 7.72 (411%) | 0.71 | 25.9 | 43.1 | 2.23 |
| 50% NPK + 50% N as FYM | 100 % NPK | 5.30 (135) | 2.85 (265) | 8.01 (430%) | 0.79 | 26.7 | 42.7 | 2.14 |
| 75% NPK + 25% N as FYM | 75 % NPK | 5.08 (126) | 2.63 (237) | 7.09 (369%) | 0.69 | 26.1 | 42.8 | 2.20 |
| 50% NPK + 50% N as WS | 100 % NPK | 4.90 (117) | 2.78 (256) | 7.32 (384%) | 0.64 | 25.8 | 38.2 | 1.96 |
| 75% NPK + 25% N as WS | 75 % NPK | 4.77 (112) | 2.50 (221) | 6.82 (351%) | 0.61 | 24.3 | 36.6 | 2.00 |
| 50% NPK + 50% N as GLM | 100 % NPK | 5.58 (148) | 2.98 (282) | 7.97 (427%) | 0.83 | 26.8 | 42.1 | 1.91 |
| 75% NPK + 25% N as GLM | 75 % NPK | 5.15 (128) | 2.65 (239) | 7.08 (368%) | 0.68 | 24.9 | 38.9 | 2.09 |
| FP ($N_{40}P_{20}$ + 3 t FYM/ha) | FP ($N_{40}P_{20}$ /ha) | 3.50 (55) | 1.75 (124) | 5.44 (266%) | 0.42 | 17.2 | 19.4 | 1.6 |
| | SEm± | 0.10 | 0.05 | | | | | |
| | CD (P=0.05) | 0.29 | 0.18 | | | | | |

Cost of rice and wheat is ₹650/q and 1,200/q respectively; *Figures in parentheses are percentage enhancement over the control; FYM, Farmyard manure; WS, Wheat straw; GLM, Green-leaf manure; FP, Farmers practice; WEY, Wheat-equivalent yield; SYI, Sustainable yield index; NMR, Net-monetary returns

**Table 3.** Changes in organic carbon, N, P, K, S and Zn up to end of 2010–11 under different treatments

| Treatment | | pH | EC | BD | OC | Available nutrients (kg/ha) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Kharif* | *Rabi* | | (dS/m) | (g/cm$^3$) | (g/kg) | N | P | K | S | Zn |
| Control (no fertilizer, no manure) | Control | 7.53 | 0.51 | 1.37 | 6.0 | 246 | 8.5 | 284 | 6.3 | 0.24 |
| 50% NPK | 50% NPK | 7.64 | 0.55 | 1.36 | 6.3 (5%)* | 258 (4.9%) | 8.9 (4.7%) | 315 (1.92%) | 7.1 (12.7%) | 0.25 (4.2%) |
| 50% NPK | 100% NPK | 7.58 | 0.57 | 1.35 | 6.6 (10%) | 263 (6.9%) | 9.1 (7.1%) | 334 (17.61%) | 7.0 (11.1%) | 0.31 (29.2%) |
| 75% NPK | 75% NPK | 7.64 | 0.54 | 1.34 | 6.6 (10%) | 268 (8.9%) | 10.6 (24.7%) | 369 (29.93%) | 7.2 (14.3%) | 0.31 (33.3%) |
| 100% NPK | 100% NPK | 7.63 | 0.50 | 1.34 | 6.9 (15%) | 270 (9.8%) | 13.5 (58.8%) | 431 (51.76%) | 7.2 (14.3%) | 0.32 (33.3%) |
| 50% NPK + 50% N as FYM | 100% NPK | 7.49 | 0.58 | 1.27 | 7.6 (26.7%) | 282 (14.6%) | 15.4 (81.2%) | 466 (64%) | 8.4 (33.3%) | 0.43 (79.2%) |
| 75% NPK + 25% N as FYM | 75% NPK | 7.57 | 0.55 | 1.28 | 7.5 (25%) | 279 (13.4%) | 15.9 (87.1%) | 461 (62.3%) | 8.2 (30.2%) | 0.40 (66.7%) |
| 50% NPK + 50% N as WS | 100% NPK | 7.53 | 0.57 | 1.31 | 7.6 (26.7%) | 280 (13.8%) | 15.8 (85.9%) | 487 (71.5%) | 8.1 (28.6%) | 0.39 (62.5%) |
| 75% NPK + 25% N as WS | 75% NPK | 7.57 | 0.53 | 1.32 | 7.5 (25%) | 279 (13.4%) | 17.0 (100%) | 466 (64%) | 8.3 (31.8%) | 0.36 (50%) |
| 50% NPK + 50% N as GLM | 100% NPK | 7.48 | 0.63 | 1.27 | 7.9 (31.7%) | 292 (18.7%) | 17.2 (102.4%) | 488 (71.8%) | 8.5 (34.9%) | 0.45 (87.5%) |
| 75% NPK + 25% N as GLM | 75% NPK | 7.58 | 0.54 | 1.28 | 7.6 (26.7%) | 281 (14.23%) | 16.9 (98.8%) | 474 (66.9%) | 8.2 (30.2%) | 0.41 (70.8%) |
| FP ($N_{40}P_{20}$ + 3 t FYM/ha) | FP ($N_{40}P_{20}$ /ha) | 7.64 | 0.48 | 1.36 | 7.2 (20%) | 272 (10.6%) | 14.7 (72.9%) | 440 (54.9%) | 7.9 (25.4%) | 0.37 (54.2%) |
| | Initial | 7.62 | 0.55 | 0.39 | 6.5 | 240 | 16.0 | 488 | 7.8 | 0.35 |

*Figures in parenthesis are percentage enhancement over the control; FYM, Farmyard manure; WS, Wheat straw; GLM, Green-leaf manure; FP, Farmers practice; EC, Electrical conductivity; BD, Bulk density; OC, Organic carbon

in organic carbon content over unfertilized control plot and imbalanced nutrients managed treatments (50–50% of recommended NPK to rice and wheat; 50% NPK to rice and 100% NPK to wheat; 75–75% NPK to rice and wheat; and 100–100% NPK to rice and wheat). The increase in organic carbon level in the control, reduced (6.0 g/kg) from the initial status (6.5 g/kg). The increase in organic carbon content (Table 3) due to use of chemical fertilizer, direct incorporation of organic matter through GLM, FYM and WS can be attributed to higher contribution of biomass to the soil in the form of better root growth, crop residues and biomass (Katyal *et al.,* 2003; Ghathala *et al.,* 2007).

### *Soil nutrient status and biological properties*

The available N, P, K, S and Zn content was higher under balanced nutrition, whereas reduction in above parameters was noted under imbalanced nutrient management. Application of 50% NPK + 50% N substituted through GLM or FYM to rice and 100% NPK to wheat increased to the tune of 18.7, 102.4, 71.8, 34.9 and 87.5% available N, P, K, S and Zn respectively over the control (Table 3). The release of organic acids and other microbial products through the mineralization of organic matter might have influenced the availability of all these essential nutrients (Katyal *et al.*, 2003). While discussing the biological properties of soil after completion of 25 crop cycle on same field with the same lay-out plan, nutrient supplied through organic sources along with chemical fertilizer (Table 4) had higher microbial population (total fungi, bacteria, azotobacter, phosphorus-solubilizing bacteria and actinomycetes) than the control and fertilizer treatment (Upadhyay *et al.,* 2011).

It can be concluded that over 25 years in rice–wheat cropping sequence, treatment receiving organic manure along with reduced dose (50 or 25%) of chemical fertilizers provide higher production efficiency and system productivity along with improvement in soil health. Organic manure are not only a substitute, but a supplement of chemical fertilizers result in build up of organic carbon, available N, P and K and sustain soil pH and EC as compared with chemical fertilizer alone.

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**Table 4.** Changes in biological properties up to end of 2010–11 under different treatments

| Treatment *Kharif* (rainy season) | *Rabi* (winter season) | Fungi ($10^4$/g) | Bacteria ($10^6$/g) | AZB ($10^6$/g) | PSB ($10^6$/g) | ACT ($10^7$/g) |
|---|---|---|---|---|---|---|
| Control (no fertilizer, no manure) | Control | 34.0 | 29.3 | 8.6 | 4.6 | 4.9 |
| 50% NPK | 50% NPK | 38.5 | 35.2 | 17.3 | 8.0 | 5.8 |
| 50% NPK | 100% NPK | 40.9 | 37.0 | 17.0 | 8.9 | 6.3 |
| 75% NPK | 75% NPK | 41.6 | 39.5 | 21.3 | 11.6 | 6.0 |
| 100% NPK | 100% NPK | 42.2 | 42.5 | 24.7 | 12.0 | 6.9 |
| 50% NPK + 50% N as FYM | 100% NPK | 49.0 | 58.0 | 33.9 | 18.0 | 12.4 |
| 75% NPK + 25% N as FYM | 75% NPK | 45.4 | 55.5 | 31.5 | 15.9 | 9.2 |
| 50% NPK + 50% N as WS | 100% NPK | 48.0 | 56.4 | 32.2 | 17.2 | 11.5 |
| 75% NPK + 25% N as WS | 75% NPK | 45.0 | 52.8 | 30.0 | 15.0 | 9.2 |
| 50% NPK + 50% N as GLM | 100% NPK | 53.8 | 46.2 | 37.2 | 20.3 | 14.6 |
| 75% NPK + 25% N as GLM | 75% NPK | 47.0 | 43.5 | 33.1 | 18.0 | 12.1 |
| FP ($N_{40}P_{20}$ + 3 t FYM/ha) | FP ($N_{40}P_{20}$/ha) | 44.1 | 43.8 | 27.0 | 13.4 | 7.5 |
| | Initial | NA | NA | NA | NA | NA |

FYM, Farmyard manure; WS, Wheat straw; GLM, Green-leaf manure; FP, Farmers practice; AZB, Azotobacter; PSB, Phosphorus solubilising bacteria; ACT, Actinomycetes

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