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Long-term Effect of Integrated Nutrient Management on Chemical and Microbial Properties of Soil under Rice (*Oryza sativa* L.)-Wheat (*Triticum aestivum* L.) System in an Acid Alfisol

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Authors' contributions

This work was carried out in collaboration between all authors. Author SS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SKS managed the analyses of the study. Authors IK and SD managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of the investigation was to see the long-term effect of integrated nutrient management (INM) on chemical and microbiological properties of soil after 17 cycles of a rice-wheat cropping system.
Place and Duration of Study: This study was carried out in an on-going long-term fertilizer experiment initiated during 1991 at CSK Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh, India.
Methodology: The experiment comprised of 8 treatment combinations viz., N, P and K fertilizer

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application as individual component and use of chemical fertilizers in conjunction with different organic sources i.e. farm yard manure (FYM), wheat straw (WS), and green manure (GM) with *Sesbania aculeata* to substitute 25 or 50% N through organics.

Results: The highest grain yield was 43.37 q ha^{-1} in treatment receiving 50% NPK + 50% N through FYM and lowest of 26.70 q ha^{-1} under control. The highest increase of organic carbon of about 55.2 per cent over control was observed under treatment receiving 50% N substituted through FYM during summer every year. Similarly, the highest soil microbial biomass carbon (248.50 mg kg^{-1}), microbial biomass nitrogen (38.25 mg kg^{-1}) and respiratory activities (153 mg kg^{-1}) was observed in the same treatment. Total nitrogen was highest (928 mg kg^{-1}) under 50% NPK + 50% N through green manure in summer followed by 100% NPK in winter.

Conclusion: Application of 50% N through organics plus 50% NPK through chemical fertilizers was better than other treatments in improving chemical and microbiological properties of soil and in sustaining the crop yields.

Keywords: Long term field experiment; organic manures; rice-wheat; soil properties.

1. INTRODUCTION

The high input farming dependent on fertilizers has adversely influenced the physico-chemical and biological properties of soil besides over exploitation of water resources. The production system of rice-wheat, however, is very exhaustive and has resulted in stagnation in the yield of both the constituent crops [1]. Cultivation of two cereals in a year on a same piece of land leads to soil fertility problems and soils are showing signs of fatigue, as judged by stagnation in yields of rice and wheat as well as a lower response to applied inorganic fertilizers. Thus, need of the hour is to go in for an environmentally sustainable crop input management technology which is economically viable, socially acceptable and implementable.

Integrated nutrient management is one of the most important components of the production technology to sustain soil fertility and crop productivity. The combined use of organic and inorganic sources of plant nutrients not only pushed the production and profitability of field crops but also helped in maintaining the fertility status of the soil [2]. The advantage of combining organic and inorganic sources of nutrients in integrated nutrient management has been proved superior to the use of each component separately [3]. Though, the fertilizers have played a prominent role in increasing the productivity of crops in the country, but continuous imbalanced use of fertilizers caused deterioration of soil health. Organic manures improve soil chemical and biological properties and, thus, enhance crop productivity vis-à-vis maintain soil health. Organic manures contain plant nutrients though in small quantities in comparison to the chemical fertilizers, the presence of growth hormones and enzymes make them essential for improvement of soil fertility and productivity. The effects of organics on soil microorganisms have also received particular attention. Following application of bio-solids the size and activity of soil microbial biomass, which is widely recognized as an important agent in soil organic turnover, might be generally expected to increase in response to added C and N as well as other nutrients [4]. The effect of management practices on soil fertility criteria are best evaluated using long-term field experiments. Therefore experiment was conducted in the ongoing field experiment on rice-wheat cropping system initiated in 1991 with the objective to compare the effect of continuous application of different organic residues with those of mineral fertilizer on chemical soil parameters as well as on the size and activity of the soil microbial community.

2. MATERIALS AND METHODS

2.1 Experimental Site

The present study was undertaken at Padhiarkhar experimental Farm of Department of Agronomy, Forages and Grassland Management, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India (located at 32°6´ N latitude, 76°3 ′ E longitude and 1223.7 m altitude in North-West Himalayas), during 2008-09 in the on going field experiment on rice-wheat cropping system initiated in 1991. The region receives an average rainfall of 2600 mm per annum, major portion of which (80%) is received during June to September. Mean monthly meteorological data during the crop season has been presented in Fig. 1. The soil of the experimental area was classified as Typic Hapludalf and was silty clay loam in texture, acidic in reaction (pH 5.5) having CEC 11.5 c mol (p^+) kg^{-1}, organic carbon 6.0 g kg^{-1}, and available nitrogen (N), phosphorus (P) and potassium (K) 675, 21.9 and 221 kg ha^{-1}, respectively.

2.2 Experimental Details

Rice followed by Wheat was grown in sequence at the same site with 8 treatments in randomized block design having four replications. The treatment detail has been given in Table 1. Transplanting of rice crops during *Kharif* 2008 was done with spacing of 20 x 15 cm^2 on 4th July, 2008. The variety used was HPR-2143 and 2-3 seedlings were transplanted per hill. The crops were irrigated only twice and thereafter it met its water requirement through rainfall. Weed control was done chemically with the application of Butachlor. Wheat crops during *rabi,* 2008-09 was sown on 15th November, 2008 and the varieties used was HPW 155. The recommended doses used in 100% N, P and K was 90:17:33 and 120:26:25 for rice and wheat, respectively. In rice, half of N and entire quantity of P and K were applied as basal dose through urea, superphosphate and muriate of potash, respectively. The remaining half dose of N was applied at tillering stage. The organics *viz*. farmyard manure, wheat cut straw and *Dhaincha* as green manure were applied to rice crop only in the specified treatments. In wheat 1/3rd of N and entire amount of P and K were applied as basal dose and remaining 2/3rd dose of N in two splits at tillering and grain filling stage through urea, superphosphate and muriate of potash, respectively. In farmers' practice, FYM 5 t ha^{-1} was applied along with 40% NPK to rice followed by 40% NPK to wheat.

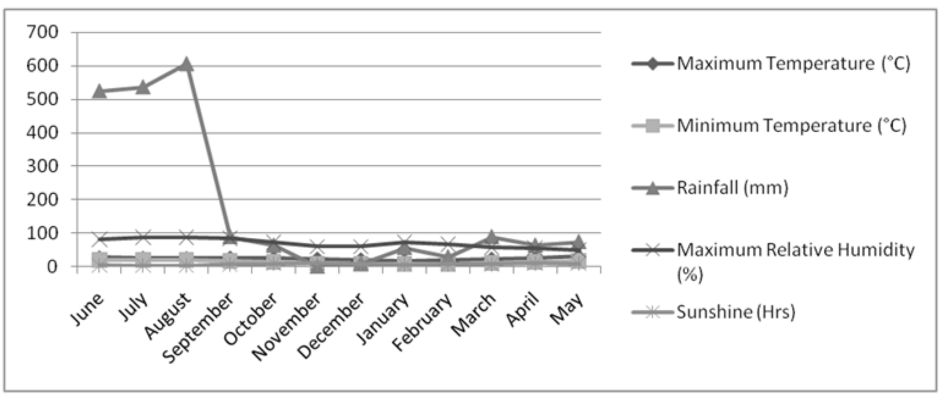

Fig. 1. Mean monthly weather data at Palampur during 2008-09

Table 1. Detail of treatments

Treatment	*Kharif*	*Rabi*
T_1	Control	Control
T_2	50% NPK	50% NPK
T_3	50% NPK	100% NPK
T_4	75% NPK	75% NPK
T_5	100% NPK	100% NPK
T_6	50% NPK+50% N through FYM	100% NPK
T_7	75% NPK+25% N through FYM	75% NPK
T_8	50% NPK+50% N through wheat cut straw	100% NPK
T_9	75% NPK+25% N through wheat cut straw	75% NPK
T_{10}	50% NPK+50%N through Green manure (*Dhaincha*)	100% NPK
T_{11}	75%NPK+25%N through Green manure (*Dhaincha*)	75% NPK
T_{12}	Farmers' practice (40% NPK+5t FYM ha^{-1})	Farmers' practice (40% NPK)

2.3 Soil Sampling

After completion of 17th cropping cycles of rice-wheat, composite samples of soil (0-0.15 m) were collected. Soil samples were placed in a cool box (+4℃) immediately in the field and afterwards sieved (2 mm mesh). One part was air dried and stored at room temperature for determination of chemical properties. The other part was kept field moist and stored sealed at -20℃ for microbiological analysis.

2.4 Soil Analysis

Soil chemical properties *viz* pH, organic carbon and total nitrogen were determined by standard procedures given by [5,6,7], respectively. Microbiological properties of soil *viz* biomass carbon, nitrogen and soil respiration were determined by the procedures given by [8,9,10], respectively.

2.5 Statistical Analysis

All data were analysed by one-way ANOVA and the differences in mean were compared by the least significant difference test at P = 0.05 [11]. Yield responses to individual soil properties were modelled with correlation index at 1% probability.

3. RESULTS AND DISCUSSION

3.1 Chemical Properties of Soil

Soil pH decreased with application of inorganic fertilizers alone from 5.5 in control to 5.3 in 100% NPK (Table 2). Application of chemical fertilizers alone resulted in decline in pH of the soil from the initial status of 5.5, whereas, with integrated application of chemical fertilizers and organics resulted in increase of pH of soil over the initial status. When inorganic and organic treatments were compared, soil pH was higher in treatments where integrated use of chemical fertilizers and manures was done.

Application of chemical fertilizers alone or in conjunction with organics increased the organic carbon content of the soil over control. It varied from 5.8 g kg^{-1} under control to 9.0 g kg^{-1} in the treatment receiving 50% NPK+50% N through FYM during summer followed by 100% NPK during winter. The highest increase of about 55.2 per cent over control and initial status, respectively, was observed under treatment receiving 50% N substituted through FYM during summer every year (Table 2). Total-N content of soil varied from 466 mg kg^{-1} under control to 928 mg kg^{-1} under 50% NPK + 50% N through green manure in summer followed by 100% NPK in winter (Table 2). Application of organics along with fertilizers resulted in increase in total-N status over chemical fertilizer alone treatment. The 50% replacement of N through any of the organic source was significantly superior over 25% replacement through respective source and green manure was found to be superior over rest of the organic sources.

3.2 Microbial Properties of Soil

The data in Table 2 revealed that application of fertilizers alone or in combination with organics significantly increased the microbial biomass carbon over control. It varied from a lowest of 168 mg kg^{-1} soil in the plots where no manure or fertilizer was used to a highest value of 248.50 mg kg^{-1} soil in the plots which received 50% NPK along with 50% N through FYM during summer and 100% NPK during winter over the years. Long-term application of organics *viz*. FYM, wheat cut straw or green manure led to a substantial increase in microbial biomass carbon over rest of the treatments. The plots which received 50% NPK along with 50% of N substituted with different organic materials recorded a significant increase in microbial biomass carbon content over the plots where only 25% of N substitution was done.

Similar to the soil biomass carbon different treatments also had significant effect on the microbial biomass nitrogen and it varied from a minimum of 21 mg kg^{-1} in control to a maximum of 38.25 mg kg^{-1} where 50% NPK plus 50% N through FYM to rice followed by 100% NPK to wheat was applied (Fig. 2). Highest value of soil biomass nitrogen was recorded in plots which received 50% NPK along with 50% N through FYM during summer and 100% NPK during winter over the years.

Microbial biomass alone does not provide information on microbial activity. Therefore measurements of microbial biomass turnover, such as soil respiration, which is considered to reflect the availability of carbon for microbial maintenance, are required for that assessment. In our experiment variation in respiratory activity was from 118 mg kg^{-1} of soil where no fertilizer or manure was applied to the crops to 153 mg kg^{-1} of soil under 50% NPK along with 50% N through FYM (Fig. 3). The increase in carbon dioxide evolution under integrated use of 50% NPK and

50% N either through FYM, wheat cut straw or green manure over control was worked out to be 29.7, 18.6 and 14.4 per cent, respectively. Substitution of 25% N through either of organics resulted in lower carbon dioxide evolution in comparison to 50% substitution.

3.3 Crop Yields

In our experiment highest grain yield of paddy 43.37 q ha^{-1} was recorded in treatment receiving 50% NPK + 50% N through FYM during summer followed by 100% NPK during winter and lowest of 26.70 q ha^{-1} under control. Application of 100% NPK significantly increased grain yield over control by 44.3 per cent. Rice straw yield also followed almost similar trend as followed by the rice grain yield and it varied from a minimum of 31.54 q ha^{-1} under control to a maximum of 73.12 q ha^{-1} in plots which received 50% N substituted through FYM during summer followed by 100% NPK during winter (Fig. 4). Conjoint use of chemical fertilizers and organic manures also significantly increased grain yield of rice over control. Substitutions of 50% N through any of the organics recorded higher yields as compared to 25% substitution, the differences, however, were not significant.

3.4 Relationship of Soil Properties with Crop Yield

Grain and straw yield was positively and significantly correlated with all the chemical and microbiological soil properties except pH (Table 3). The values of coefficient of correlation of grain and straw yield with microbial biomass carbon were 0.90 and 0.85, respectively showing highest correlation followed by organic carbon (0.87 and 0.83, respectively) and total nitrogen (0.87 and 0.82, respectively). Correlation coefficient values for grain and straw yield with soil respiration was 0.74 and 0.80, respectively.

Table 2. Influence of long-term application of organics and fertilizers on soil pH, total N, organic C and Microbial C (soil samples were taken from soil layer from 0.0-0.15 m after the harvest of wheat 2008-09)

Treatment			pH	Total nitrogen (mg/kg)	Organic carbon (g/kg)	Microbial carbon (mg/kg)
Rice		Wheat				
T_1	Control	Control	5.5	466	5.8	168.00
T_2	100% NPK	100% NPK	5.3	723	7.5	211.75
T_3	50% NPK+50% N through FYM[a]	100% NPK	5.6	876	9.0	248.50
T_4	75% NPK+25% N through FYM	75% NPK	5.6	807	8.6	242.50
T_5	50% NPK+50% N through WS[b]	100% NPK	5.6	796	8.4	238.50
T_6	75% NPK+25% N through WS	75% NPK	5.5	733	7.7	230.50
T_7	50% NPK+50% N through GM[c]	100% NPK	5.5	928	8.3	241.50
T_8	75% NPK+25% N through GM	75% NPK	5.5	842	7.5	234.50
P = 0.05			0.07	16	0.43	3.37

[a]farmyard manure, [b]wheat straw, [c]green manure

Table 3. Correlation coefficients (r) of different soil properties (0-0.15 m) with grain and straw yield of paddy (2009)

Soil properties	Grain yield	Straw yield
pH	0.22	0.40
Organic carbon	0.87*	0.83*
Total nitrogen	0.87*	0.82*
Biomass carbon	0.90*	0.85*
Biomass nitrogen	0.83*	0.84*
Soil respiration	0.74*	0.80*

** significant at 1 % level*

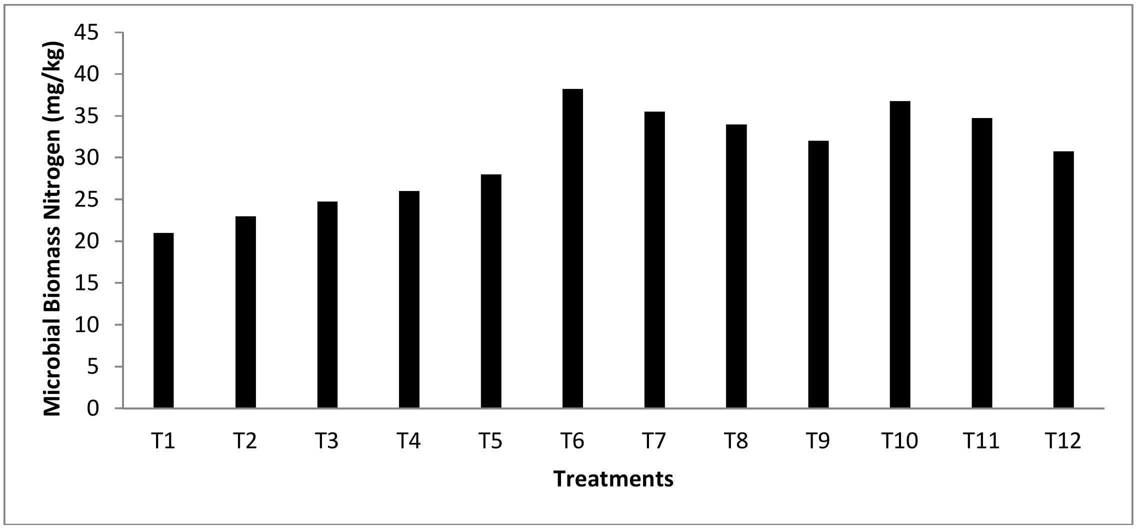

Fig. 2. Influence of long-term application of organics and fertilizers on soil microbial biomass nitrogen ($LSD_{0.05}$=1.62) (soil samples were taken from soil layer from 0.0-0.15 m after the harvest of wheat 2008-09)

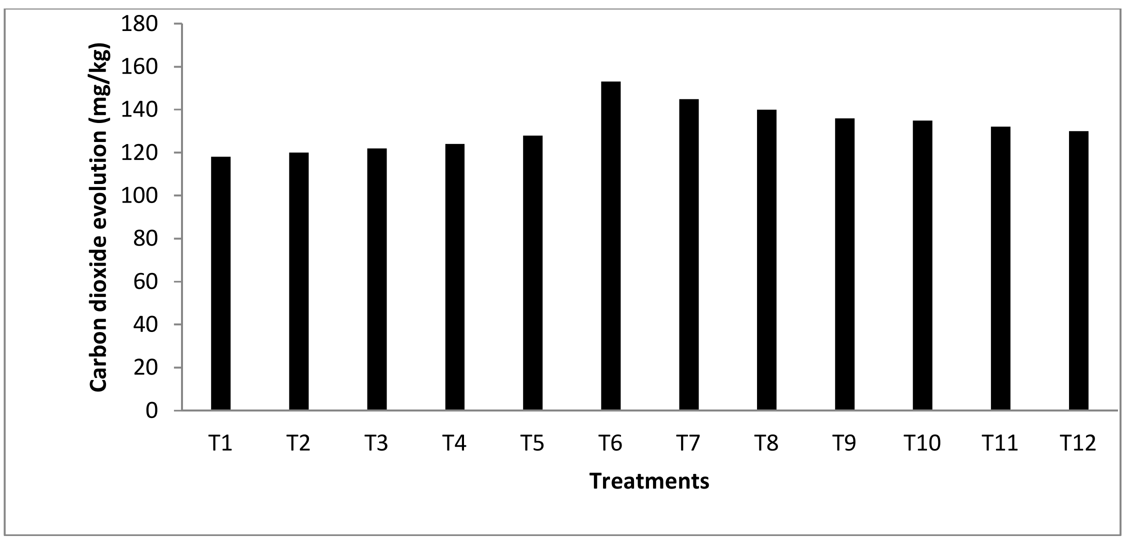

Fig. 3. Influence of long-term application of organics and fertilizers on soil respiration ($LSD_{0.05}$=9.16) (soil samples were taken from soil layer from 0.0-0.15 m after the harvest of wheat 2008-09)

3.5 Discussion

3.5.1 Chemical properties

The decline in pH due to the application of chemical fertilizers alone could be attributed to the acid producing nature of nitrogenous fertilizers [12] which, upon nitrification, release H^+ ions which are potential source of soil acidity. Soil pH was higher in treatments with integrated use of chemical fertilizers and manures which might be due to moderating effect of organic manures as it decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelation effect of organic molecules. Improvement in soil organic carbon status in plots treated with different organics continuously for 17 cropping cycles may be due to the stimulating effect of organics on growth and activity of microorganisms. This effect is further enhanced by addition of NPK fertilizers that improved the root and shoot growth. Higher production of root biomass might have increased the organic carbon content. Slow rate of organic matter decomposition in wet temperate zone could be another reason for build-up of soil organic carbon [13]. The increase in total-N content with continuous application of fertilizers alone or in combination with organics for 17 years may be ascribed to the increase in different organic and inorganic N fractions in the present study.

3.5.2 Microbial properties

Higher stress due to no use of nutrients in control restricted crop production and thus carbon substrate (root exudates) with consequent reduction in biomass carbon. The readily available carbon fraction of FYM, wheat cut straw or green manure supported the development of microbial biomass that increased soil microbial biomass carbon in treatments where integrated use of chemical fertilizers and organic manures was done. These results are in accordance with the findings of [14]. Integrated application of chemical fertilizers and manures resulted in higher microbial biomass nitrogen. Organic manures are not only rich in carbon but also in other macro and micronutrients including nitrogen though the availability of nutrients to crop from manures is generally lower than from inorganic sources because of their slow release from organically bound sources. Application of chemical fertilizers along with manures resulted in supply of nutrients in balanced proportion which was reflected in terms of increased amount of microbial biomass nitrogen. These results are in accordance with [15].

There is evidence showing that the use of organic manures can increase soil CO_2 evolution [16]. Substitution of 25% N through either of organics resulted in lower carbon dioxide evolution in comparison to 50% substitution. Differences in soil respiration between treatments are indicative of variable amounts of organic carbon accumulated with different organics as well as varying stability of organic carbon [17]. It has also been well documented that soil CO_2 evolution is a function of root biomass [18].

3.5.3 Crop yields

The integrated use of chemical fertilizers with organic manures *viz.* FYM, wheat cut straw or green manure might have added huge quantity of organic matter in soil which improved the chemical and microbiological properties of soil that resulted in increased productivity of crop by increasing availability of plant nutrients [19]. Conjoint use of chemical fertilizers and organic manures also significantly increased grain yield of rice over control. Substitutions of 50% N through any of the organics recorded higher yields as compared to 25% substitution, the differences, however, were not significant.

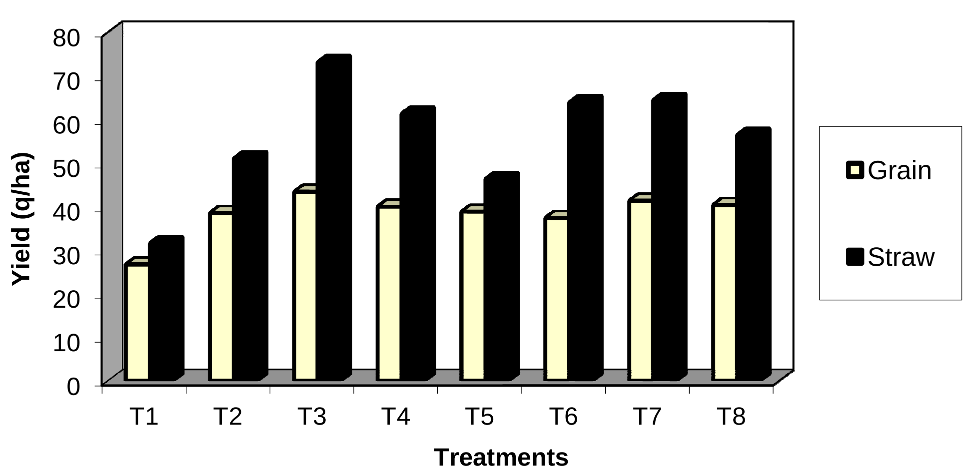

Fig. 4. Influence of long-term application of organics and fertilizers on grain and straw yield of rice 2009 ($LSD_{0.05}$=4.23 & 8.75 for grain and straw yield, respectively)

4. CONCLUSION

Application of organics is a promising soil management practice which can improve soil chemical and microbiological properties. Substitution of 50% N through any of the organics was found to be better than 25% substitution through any of the organics in sustaining the crop yield and improving chemical and microbiological properties of soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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