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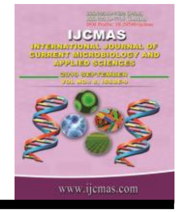

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Crop Productivity and Soil Biological Properties Influenced by Long Term Application of Mineral Fertilizers and Manures under Rice-Wheat Sequence on Mollisols of Northern India

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A B S T R A C T

The rice-wheat cropping system, which is considered as the backbone of food self-sufficiency, is facing a sustainability problem due to practices of modern production system with indiscriminate use of chemical fertilizers and pesticides. So, effects of long term use of mineral fertilizers and farmyard manure (FYM) under rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system in a Mollisol was investigated. Rice and wheat yields were highest (51.47 and 48.60 q ha^{-1}, respectively) with 100% NPK + 15 t FYM ha^{-1} and lowest in control (13.72 and 11.85 q ha^{-1}, respectively). Balanced fertilizers use of (100% NPK + Zn) was also at par with 100% NPK + FYM treatment in rice and wheat yields. The FYM amended treatment gave the highest and significantly more counts of bacteria, fungi and actinomycetes in all four depths of soil (0-15cm, 15-30cm, 30-45cm and 45-60cm) as compared to all other treatments after crop harvest. The observed microbial biomass C with 100% NPK + FYM in four soil depths were (413.36, 193.50, 100.11 and 66.41 after rice and 435.93, 235.54, 142.64 and 82.41 µg g^{-1} after wheat, respectively, which was highest and significantly higher over all other treatments. Soil enzymes dehydrogenase, acid and alkaline phosphatase and urease activities were significantly higher with 100% NPK + 15 t FYM ha^{-1} than all the other treatments. Mineral fertilizer treatments with 100% NPK and 150% NPK were comparable and significantly better than application of 50% NPK, 100% N and 100% NP in different soil biological properties. Application of Zn with 100% NPK increased the crop yields and soil biological properties over 100% NPK. Imbalanced use of mineral fertilizers had the harmful effect on soil biological health.

Introduction

The rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) cropping system occupies about 28.8 million hectares mainly spread over Asia's five countries, namely, India, Pakistan, Nepal, Bangladesh and China (Timsinia and Connor, 2001; Prasad, 2005). Rice-wheat cropping system followed in Indo-Gangatic plains of India is also a main cropping system of newly carved Uttarakhand state. This signifies the contribution of rice-wheat cropping system in meeting food requirements of the country. The rice-wheat cropping system, which is considered as the backbone of food self-sufficiency, is however facing a sustainability problem due to practices of modern production system with indiscriminate use of chemical fertilizers and pesticides (Duxbury *et al.,* 2000; Ladha *et al.,* 2000; Prasad, 2005). The production of both these crops has increased remarkably with the development of high-yielding and fertilizer responsive crop varieties (Ram *et al*., 2011). The rice–wheat cropping system is highly nutrient exhaustive and annually removes about 650 kg N, P and K ha^{-1} and 0.5–1.0 kg ha^{-1} Zn (Shah *et al.,* 2011). This has led to a noticeable increase in fertilizer use in these crops; about 65% of the total fertilizer consumed in India for these two crops (Yadav and Kumar, 2009). According to Ladha *et al.,* (2003) and Manna *et al.,* (2005), fertilizer consumption in the country is on the rise, the productivity of rice and wheat crops started showing fatigue at many locations in this cropping system. The stagnation and declining trends in yields in the rice–wheat cropping system in Asia have been reported to be mainly due to over-exploitation of soils, imbalanced use of plant nutrients (Yadav *et al.,* 2000) and deterioration in soil physical conditions. Several workers have reported the benefit of organic manure in improving and sustaining the production of rice-wheat system. Farmyard manure is house hold organic manure obtain due to microbial activity and contains large number of microbial population. Application of farm yard manure can increase the microbial activity in the soil both by activating the microbial activity through supplying C and nutrients to heterotrophic microorganisms (Gaur *et al*., 1990). There are some indications that integrated use of organic and inorganic fertilizer improves biological properties of soil (Ram *et al*., 2015). Large numbers of report are available in the literature to show the enhanced microbial activity by application of farmyard manure (Bhatt *et al*., 2016). There are very few studies on microbial population and enzymatic activities with respect to fertilizer and manure application. Therefore, this study was planned to find out the effect of long term application of fertilizer and manure on crop productivity microbial biomass and enzymatic activities of soil with rice-wheat cropping system on a Mollisols of Northern India.

Materials and Methods

Experimental site

The present study is apart of an ongoing long-term fertilizer experiment with a rice-wheat cropping system, was started with wet-season rice in 1971 at the Norman E. Borlaug Crop Research Centre of the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (29° N, 79.3° E, 243.2 m above sea level) located in the foothill soils of the tarai region of Udham Singh Nagar district of Uttrakhand, India. The experimental field was brought under the rice and wheat cultivation on a forested ecosystem. The mean annual rainfall is about 1400 mm, of which 80–90% is received between June and September. Mean maximum and minimum temperatures ranged between 35 and 18 °C during rice and 25 and 2 °C during wheat crops, respectively. At the start of the experiment, the soil was poorly drained, and had high organic carbon, nitrogen, and zinc. The rainfall received during cropping period was 1116.3 mm in 2016-2017, the experimental soil was classified under sub-group Aquic hapludoll in order Mollisols (Deshpande *et al*., 1971). The soil had silty clay loam texture (sand: 32%, silt: 39%, clay: 29%,), with pH 7.30 and electrical conductivity 0.35 dS m^{-1} (in soil:water ratio of 1:2.5), cation exchange capacity 20.0 cmol (p+) kg^{-1}, soil organic C 14.8 g kg^{-1}, alkaline $KMnO_4$ extractable N 392 kg ha^{-1}, 0.5 M $NaHCO_3$ extractable P 18 kg ha^{-1} and 1 N ammonium acetate extractable K 125 kg ha^{-1} (Ram, 1995).

Treatments details

The nutrient treatments being used for rice and wheat crops since 1971 were T1 [50% Nitrogen, Phosphorus, Potassium (NPK)], T2 (100% NPK), T3 (150% NPK), T4 [100% NPK + Zinc (Zn)], T5 (100% NP), T6 (100% N), T7 (100% NPK + farm yard manure (FYM)), T8 [100% NPK – Sulphur (S)] and T9 (unfertilized control). The 100% NPK represents the recommended fertilizer doses for each crop as determined from soil tests in 1971. The treatments were laid out in a randomized block design with plots of 25 m × 12 m size in four replications. Fertilizer doses and sources used at optimal NPK level (100% NPK) based on initial soil tests were 120 kg N ha^{-1} through urea and diammonium phosphate (DAP), 26 kg P ha^{-1} through DAP and single superphosphate and 37 kg K ha−1 through muriate of potash. The single superphosphate was not used to avoid S for treatment T8. Treatment T7 (100% NPK + FYM) received 15 t FYM ha^{-1} (0.50–0.80% N, 0.26–0.30% P, 0.45–0.50% K) in wheat before the preparation of field. It was mixed in plough layer of soil (0–15 cm) by tillage. Half dose of N and full dose of P and K were applied as basal at the time of sowing. The remaining half dose of N was applied in two equal splits after 25 and 50 days of transplanting in rice and 30 and 55 days after sowing in wheat. Since kharif, 1993, zinc was applied to rice as basal 50 kg zinc sulphate ha^{-1} (21.0% Zn) approximately at a gap of 4-5 years in treatment T1, T4, T5, T6 and T7 when Zn in soil becomes less than critical level (<1.0 ppm). In T4, Zn was also applied at the same rate as basal each year, Zinc in treatment T8 was applied as Zinc oxide (ZnO) at the same rate. Weeds were controlled by chemically using butachlor in rice (1.5 kg a.i. ha−1 at 2 days after transplanting) and pendimethaline in wheat (1.0 kg a.i. ha−1 as pre-emergence). Rice (cv. PR 113) and wheat (cv. PBW 502) were raised during the cropping season with recommended crop management practices. Irrigation was applied as per need of the field and rainfall activity. The harvested produce was sun dried for 3–4 days and weighed for recording biological yield. The grains were separated from the produce with mechanical thresher, cleaned, sun dried to approximately 12.0% moisture and weighed for recording grain yield. The straw yield was recorded by subtracting the grain yield from the biological yield.

Soil sampling and laboratory analysis

Soil samples from four depths (0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm) were collected with the help of auger from individual plots after the harvesting of rice and wheat crops. The field moist soil samples were sieved through 2 mm sieve and stored in plastic bags at 4°C in deep fridge. The population of bacteria, fungi and actinomycetes in soil was determined by serial dilution pour plate method using nutrient agar medium for bacteria, Ken Knight and Munaier's medium for actinomycetes and Martin's Rose-Bengal streptomycin agar medium for fungi (Wollum, 1982). Microbial biomass carbon (MBC) in soil samples were estimated following chloroform–fumigation–extraction procedure as described by Jenkinson and Powlson (1976) using Kc value of 0.45 for MBC (Vance *et al*., 1987). Soil dehydrogenase activity was determined by the reduction of 2,3,5-triphenyl-tetrazolium chloride to 1,3,5-triphenylformazan (TPF) by the method of Casida *et al.*, (1964). The acid and alkaline phosphatase activities in soil were determined as per the method given by Tabatabai and Bremner (1969) by using p-nitrophenyl phosphate tetrahydrate solution of pH 6.5 for acid phosphatase and pH 11.0 for alkaline phosphatase enzymes. The urease enzyme activity was done by the estimation of urea hydrolysis as described by Tabatabai (1982). The obtained data on rice and wheat yields and soil biological properties of both the years were pooled and subjected to standard analysis of variance (ANOVA) following standard procedures for randomized block design (Gomez and Gomez 1984). Correlation study was done with the help of SPSS-16 statistical package (SPSS, Inc., Chicago, IL, USA).

Results and Discussion

Rice and wheat yields

The grain and straw yields of rice and wheat both crops after harvest were highest with treatment 100% NPK + 15 t FYM ha^{-1} (Table 1). This treatment produced 44.98% and 53.84% higher rice yields and 45.07 and 53.43% higher wheat yields over 100% NPK application, respectively, and was significantly superior to all other fertilizers treatments. The pivotal role of soil microorganisms and enzymatic activities in transformation and availability of nutrient elements in soil is well documented (Nannipieri *et al*., 1990). It can also be due to improvement in soil physical conditions as a result of continuous FYM application, which provided congenial environment for plant growth and nutrient uptake (Tejada *et al*., 2009). These results are in conformity with the findings of Selvi *et al.*, (2004) and Mishra *et al.,* (2008). Application of 100% NPK + Zn was second highest by producing grain and straw yields of rice (33.71 and 32.80%) and wheat, (30.00 and 49.31%), in comparison to 100% NPK treatment, respectively. The significant positive response of Zn application with 100% NPK could be attributed to the development of Zn deficiency in soil due to continuous rice–wheat crops over the years, as reported earlier also by Ram (2000) and Varshney *et al.,* (2008). Treatments having application of 100% NP and 100% NPK-S show significantly higher yields of both grain and straw in both crops as compared to control, because these two treatments receiving zinc as well as 100% NP and 100% NPK-S. Although zinc was not applied in treatment having 100and 50% NPK. Reason behind the imbalanced fertilizer treatment of 100% N was at par with 100% NPK in rice and wheat yields may be ascribed to adequate availability of P and K in soil due to continuous addition of crop residues in the form of roots stubbles and leaf fall. These results suggested that application of FYM and Zn with 100% NPK are necessary for sustaining productivity in rice–wheat cropping system in Mollisols.

Microbial population

Application of 100% NPK + 15 t FYM ha^{-1} recorded highest population of bacteria (15.19 and 18.22 cfu × 10^8 g^{-1} soil) at surface soil of depth 0-15 cm, (12.92 and 14.00 cfu × 10^8 g^{-1} soil) at 15-30 cm, (5.69 and 7.49 cfu × 10^8 g^{-1} soil) at 30-45 cm and (2.12 and 3.65 cfu × 10^8 g^{-1} soil) at 45-60 cm in rice and wheat crops, respectively followed by 150% NPK treatment (Fig. 1). FYM incorporation along with 100% NPK fertilizers showed maximum and significantly higher fungi and actinomycetes population (39.23 cfu × 10^4 g^{-1} soil and 49.17 cfu × 10^5 g^{-1} soil) after rice and (52.29 cfu × 10^4 g^{-1} soil and 53.13 cfu × 10^5 g^{-1} soil) after wheat in surface soil, respectively (Fig. 2 and 3). Upadhyay *et al.,* (2011) and Singh *et al.*, (2012) also reported the similar results which might be attributed to the availability of adequate biomass as feed for the microbes. Decreasing trend in fungi and actinomycetes population was found with respect to soil depth. Balanced fertilizer treatment (100% NPK+Zn) recorded significantly higher bacteria, fungi and actinomycetes compared to 100% N, 100% NP and control treatments. Lower microbial population in soils after rice was observed in comparison to wheat. The 150% NPK was comparable to 100% NPK and 100% NPK+Zn in soil microbial population and suggests that supply of inorganic nutrients at higher than optimum level without organic manure cannot support microbial population in the soil. Sharma *et al*., 2016 suggested that the increase in microorganism numbers in response to chemical fertilizers may be attributed to a better nutrient status of soil and also reported that the effect was greater in the treatment where 50% substitution of N was made through FYM or wheat straw in rice. The treatment 100% NPK+Zn was statistically comparable with 100% NPK in mean counts of bacteria, fungi and actinomycetes after rice and wheat crops; however, these treatments gave significantly lower counts than 100% NPK + 15 t FYM ha^{-1} indicating organic manure incorporation has greater positive effect on microbial population in the soil. Lowest microbial population was recorded in control and 100% N. These results are in agreement with the findings of Jayathilake *et al.*, (2006) and Sharma *et al.*, (2010).

Dehydrogenase activity

The integrated use of 100% NPK along with 15 t ha^{-1} FYM showed maximum and significantly higher DHA values (353.61 µg TPF g^{-1} 24 h^{-1} in rice and 365.22 µg TPF g^{-1} 24 h^{-1} in wheat) in surface as well as lower depths soils as compared to all other fertilizer treatments (Table 2). A relatively more pronounced effect of organic manure on soil enzyme activities in comparison to the inorganic fertilizers has also been reported earlier by Chu *et al.*, (2007) and Romero *et al.*, (2010). The increase in dehydrogenase enzyme activity is attributed to the availability of higher carbon substrates, being sole sources of carbon and energy for heterotrophs. Balanced use of fertilizers (100% NPK+Zn) gave significantly higher DHA values as compared to 150% NPK treatment but significantly lesser then 100% NPK+FYM treatment. This confirms that application of balanced fertilizers NPK maintained active pools of C and N in the soil surface layer due to increased plant biomass addition in these treatments. Similar results were also reported by Bhavani *et al.*, (2017) and Gill *et al.*, (2016).Similarly, 100% NPK application recorded comparable values of DHA with 150% NPK in rice and slightly higher in wheat, which was significantly lower than 100% NPK+FYM @15 t ha^{-1}. Lowest values of DHA were observed in control and 100% N treatment after rice and wheat harvest. The decreased dehydrogenase activity under 100% N alone is associated with the redox potential of soil. The redox potential of the soil might have been increased due to accumulation of nitrate over the years following application of nitrogenous fertilizer, thereby decreasing dehydrogenase activity. These results are in accordance with Bhatt *et al.*, (2016) and Mandal *et al.*, (2007). In general, slightly higher values of DHA were recorded in soils after wheat as compared to soils after rice. The dehydrogenase activity (DHA) in soils after rice and wheat was highest under 100% NPK+FYM @ 15 t ha^{-1} treatment in all four depths. Upper surface (0-15 cm) soil has remarkably higher values of DHA after rice as well as wheat crop harvest in comparison to lower depths. The dehydrogenase activity in soil significantly increased with increasing NPK levels from 50% to 100%. Imbalanced and inadequate application of fertilizers (50% NPK, 100% NP and 100% N) caused significant decline in the dehydrogenase activity. The significantly lower dehydrogenase enzyme activity in soil with NPK(-S) treatment in comparison to 100% NPK could be viewed in line of the trend observed in microbial population and biomass due to a build-up of S deficiency in the soil as a result of continuous use of S-free fertilizers. Beneficial effects of S fertilization on the dehydrogenase enzyme activity in soil has also been reported by Niewiadomska *et al.*, (2015), being an essential constituent of several amino acids and co-enzymes that play a role in microbial metabolism.

Phosphatase activity

Irrespective of the different treatments, alkaline phosphatase enzyme activity in soil was more than acid phosphatase enzyme activity after harvest of both rice and wheat crops due to the alkaline soil condition (Eivazi and Tabatabai, 1977). Acid and alkaline phosphatase activities were significantly enhanced by NPK fertilizer application. In control it was 45.70 and 44.97 µg PNP g^{-1} h^{-1} as compared to 81.55 and 88.27 µg PNP g^{-1} h^{-1}, respectively in 100% NPK for rice (Table 3 and 4). After harvest of rice crop both acid and alkaline activities (99.42 and 120.24 µg PNP g^{-1} h^{-1}, respectively) were recorded maximum and significantly higher in 100% NPK+FYM @ 15 t ha^{-1} treatment. Significantly higher activity of phosphatase enzyme in FYM applied treatment over other treatment could be attributed to additional supply of N and C substrates through applied FYM for supporting microbial activity. Bhatt *et al*., (2016) also reported that treatment with 100% NPK + 15 t FYM ha^{-1} shows the highest acid and alkaline phosphatase activity in case of both rice and wheat crops. Balanced application of fertilizer (100% NPK+Zn) was 4.2 and 24.41per cent higher acid and alkaline phosphatase activities over treatment where Zn was not added along with 100% NPK. Mishra *et al.,* (2008), Balanced fertilization supports higher plant biomass production and contributes greater return of organic residue in soil through leaf fall and root stubbles, which in turn promote the growth and activities of microorganisms. Both acid and alkaline phosphatase activities were decreased with the soil depths after harvest of both the crops. In case of wheat these both acid and alkaline phosphatase activities were also found highest (104.72 and 123.04 µg PNP g^{-1} h^{-1}, respectively) in FYM treated plot. Garg and Bahl (2008) also found similar increase in the alkaline phosphatase activity with combined application of organic manure and inorganic fertilizers. Lowest activity of phosphatase enzyme was recorded in control after harvest of both rice and wheat crops.

Urease activity

Application of 100% NPK + FYM @ 15 t ha^{-1} recorded highest urease enzyme activity after rice and wheat (7.94 and 8.14 mg urea g^{-1} 24 h^{-1}, respectively) in surface (0-15 cm) soil while it was less in sub-surface soil and decreased continuously with the soil depth (Table 5). Urease activity being high in FYM amended treatment could be because to the continuous application of organic manure, which acts as a source of C and energy for heterotrophs and provides adequate nutrition for the growth of microorganisms and their function in terms of production of soil enzymes (Rai and Yadav, 2011).

Chhonkar and Tarafdar (1981) also found that activities of the soil enzymes were significantly and positively correlated with organic C and microbial population in the soil. Application of 100% NPK+Zn was at par with 150% NPK and gave significantly higher urease enzyme activity in soil over the imbalanced fertilizer treatments like 50% NPK, 100% NP and 100% N after harvest of both the crops. Minimum urease enzyme activity observed in control plot and 100% N. Integrated use of FYM @ 15 t ha^{-1} in combination with 100% NPK causes 32.33, 17.28 and 18.33 per cent more urease activity over 100% NPK, 150% NPK and 100% NPK+Zn. 100% NPK without Zn treatment had 11.83 per cent less urease enzyme activity as compared to 100% NPK with Zn. The favourable effects of increasing the levels of N on urease enzyme activity in the soil could be attributed to increase in microbial population as well as release of greater proportion of nitrogenous substances in root exudates that induce the urease enzyme activity (Elayaraja and Singarvel, 2011).

Table.1 Rice and wheat yields

	Rice			Wheat		
Treatments	**Grain yield**	**Straw yield**	**Total yield**	**Grain yield**	**Straw yield**	**Total yield**
50% NPK	36.43	34.20	70.63	32.90	37.97	70.87
100% NPK	35.50	39.63	75.13	33.50	37.17	70.67
150% NPK	34.88	37.97	72.85	33.20	40.03	73.23
100% NPK + Zn	47.47	52.63	100.10	43.55	55.50	99.05
100% NP	44.60	48.57	93.17	39.53	40.60	80.13
100% N	33.95	35.80	69.75	36.97	32.73	69.70
100%NPK + FYM	51.47	60.97	112.43	48.60	57.03	105.63
100% NPK(-S)	42.73	42.83	85.57	37.70	40.43	78.13
Control	13.72	16.23	29.95	11.85	13.73	25.59
SEm±	1.35	1.18	1.68	1.91	1.09	2.44
CD @ 5%	4.05	3.54	5.06	5.72	3.28	7.32

Table.2 Effect of fertilizer application with different combinations of organic and inorganic sources on soil dehydrogenase activity (µg TPF 24 h^{-1} g^{-1} soil)

	Rice				Wheat			
Treatments	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**
50% NPK	145.15	90.67	60.10	26.02	181.88	92.93	61.45	27.99
100% NPK	291.02	116.19	76.63	43.69	291.41	119.11	81.43	47.38
150% NPK	294.00	120.48	81.37	42.64	297.37	131.00	86.39	49.10
100% NPK + Zn	312.64	117.13	74.65	45.29	327.02	126.51	83.50	52.25
100% NP	143.77	91.13	67.78	38.08	171.83	97.14	74.21	45.07
100% N	120.57	87.34	54.11	32.45	142.15	95.47	71.22	40.91
100%NPK + FYM	353.61	150.67	91.48	54.12	365.22	155.90	99.09	59.17
100% NPK(-S)	148.39	94.57	64.09	33.63	160.58	98.31	74.24	41.53
Control	115.78	72.63	40.56	20.84	137.11	82.46	46.46	28.00
SEm±	1.11	0.49	0.72	0.70	1.19	1.42	0.53	0.46
CD @ 5%	3.33	1.47	2.16	2.10	3.58	4.28	1.59	1.38

Table.3 Effect of fertilizer application with different combinations of organic and inorganic sources on soil acid phosphatase activity (µg PNP h^{-1} g^{-1} soil)

	Rice				Wheat			
Treatments	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**
50% NPK	63.99	32.61	14.30	7.78	79.14	52.07	34.32	9.82
100% NPK	81.55	36.17	19.04	9.21	87.73	62.77	36.31	12.77
150% NPK	87.14	36.76	19.25	13.36	97.74	68.72	42.34	13.32
100% NPK + Zn	85.04	36.55	21.43	10.68	95.71	62.77	38.43	12.27
100% NP	69.91	29.91	14.96	9.77	81.74	50.46	36.44	9.76
100% N	61.94	28.63	13.69	7.13	73.23	39.52	29.60	7.69
100%NPK + FYM	99.42	60.61	24.47	14.29	104.72	69.28	43.41	16.35
100% NPK(-S)	77.51	34.50	18.92	8.87	82.27	53.67	37.68	10.28
Control	45.70	19.50	9.12	4.82	48.14	29.96	13.59	4.75
SEm±	1.29	1.03	0.70	0.48	1.61	1.13	0.59	0.68
CD @ 5%	3.87	3.09	2.11	1.44	4.84	3.40	1.78	2.03

Table.4 Effect of fertilizer application with different combinations of organic and inorganic sources on soil alkaline phosphatase activity (µg PNP h^{-1} g^{-1} soil)

	Rice				Wheat			
Treatments	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**
50% NPK	77.26	31.60	21.99	11.56	94.22	67.80	46.17	16.40
100% NPK	88.27	40.87	21.65	13.65	103.10	75.61	49.44	16.88
150% NPK	110.30	44.98	21.08	12.21	112.22	77.53	59.91	19.29
100% NPK + Zn	109.82	43.64	18.34	10.72	106.81	75.16	49.08	17.53
100% NP	83.58	35.00	21.37	9.91	94.51	68.24	43.91	13.66
100% N	81.32	30.36	16.04	9.51	81.74	62.80	38.49	9.50
100%NPK + FYM	120.24	52.59	26.01	14.21	123.04	89.45	58.27	20.66
100% NPK(-S)	85.78	39.72	22.12	10.39	97.76	72.79	47.31	15.40
Control	44.97	18.61	15.07	4.10	60.96	43.79	21.91	7.14
SEm±	1.52	1.73	0.81	0.62	1.05	1.15	0.98	0.57
CD @ 5%	4.54	5.19	2.42	1.86	3.14	3.45	2.95	1.71

Table.5 Effect of fertilizer application with different combinations of organic and inorganic sources on soil urease activity (mg urea g^{-1} soil $24h^{-1}$)

	Rice				Wheat			
Treatments	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**
50% NPK	4.90	3.83	1.83	0.89	5.62	4.01	2.25	1.13
100% NPK	6.00	4.92	2.23	1.19	6.69	5.42	2.75	1.44
150% NPK	6.77	5.29	2.73	1.81	6.68	5.25	3.23	2.16
100% NPK + Zn	6.71	4.82	2.59	1.86	6.82	5.34	2.80	2.18
100% NP	5.00	3.29	1.93	0.86	5.70	3.79	2.36	1.37
100% N	4.40	2.75	1.69	0.74	5.12	3.29	2.05	1.12
100%NPK + FYM	7.94	5.82	3.06	2.14	8.14	5.45	3.38	2.30
100% NPK(-S)	5.09	3.75	1.91	1.11	4.94	3.46	2.07	1.25
Control	3.97	2.57	1.53	0.53	4.19	2.48	1.74	0.79
SEm±	0.43	0.81	0.37	0.46	0.78	0.73	0.56	0.58
CD @ 5%	0.13	0.24	0.11	0.14	0.23	0.22	0.17	0.17

Table.6 Effect of fertilizer application with different combinations of organic and inorganic sources on soil microbial biomass carbon (µg g^{-1} soil)

	Rice				Wheat			
Treatments	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**
50% NPK	252.70	135.67	66.11	15.50	265.17	142.22	70.47	15.73
100% NPK	331.56	157.13	77.20	28.62	333.79	175.91	85.45	30.20
150% NPK	343.31	167.43	88.53	42.26	345.70	183.04	101.74	44.77
100% NPK + Zn	336.18	162.45	81.56	34.38	347.89	183.12	93.62	43.14
100% NP	229.42	123.77	51.22	16.54	245.44	131.53	59.85	17.07
100% N	220.96	112.96	41.68	12.99	233.29	121.00	53.39	15.26
100%NPK + FYM	413.36	193.50	100.11	66.41	435.93	235.54	142.64	82.41
100% NPK(-S)	266.77	134.94	70.20	26.66	282.21	147.56	83.78	31.86
Control	212.70	107.50	32.30	9.99	218.58	111.07	43.55	10.30
SEm±	0.81	1.25	1.07	0.92	4.17	2.23	0.75	0.79
CD @ 5%	2.45	3.77	3.21	2.77	12.51	6.70	2.27	2.39

Figure.1 Effect of fertilizer application with different combinations of organic and inorganic sources on soil bacterial population ($\times 10^8$ cfu g^{-1} dry soil)

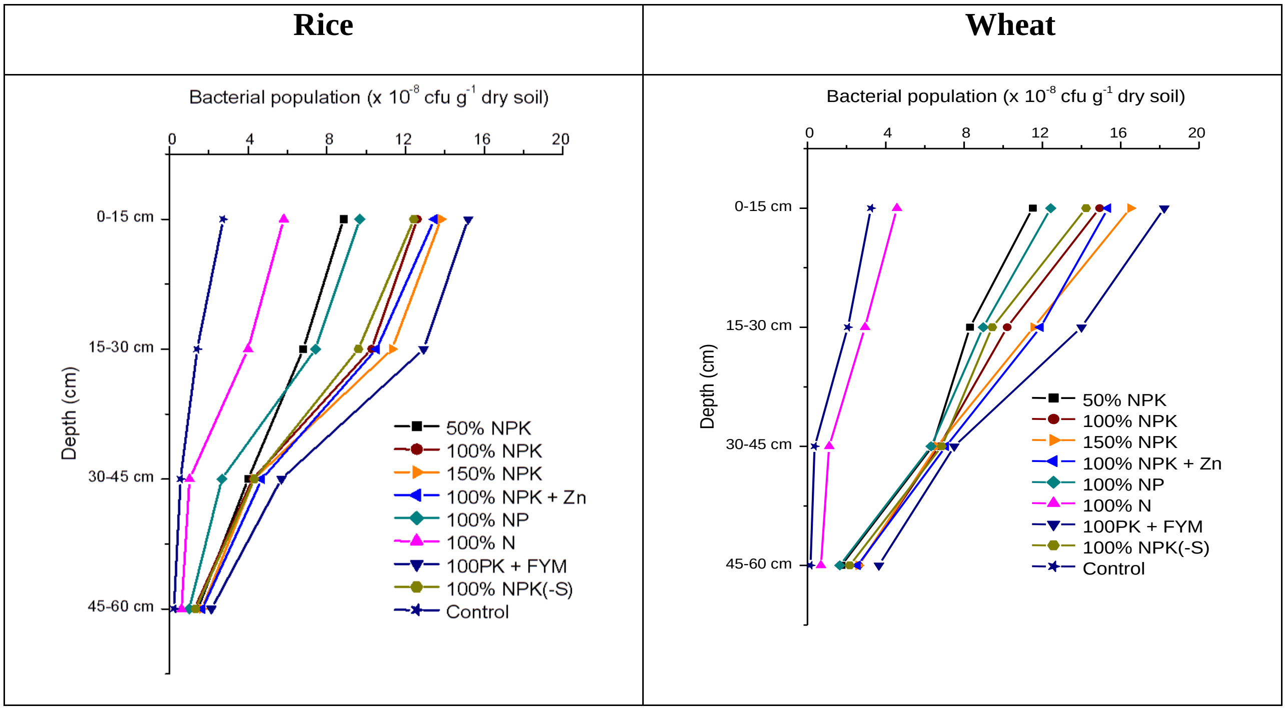


Figure.2 Effect of fertilizer application with different combinations of organic and inorganic sources on soil fungal population ($\times 10^4$cfu g^{-1} dry soil)

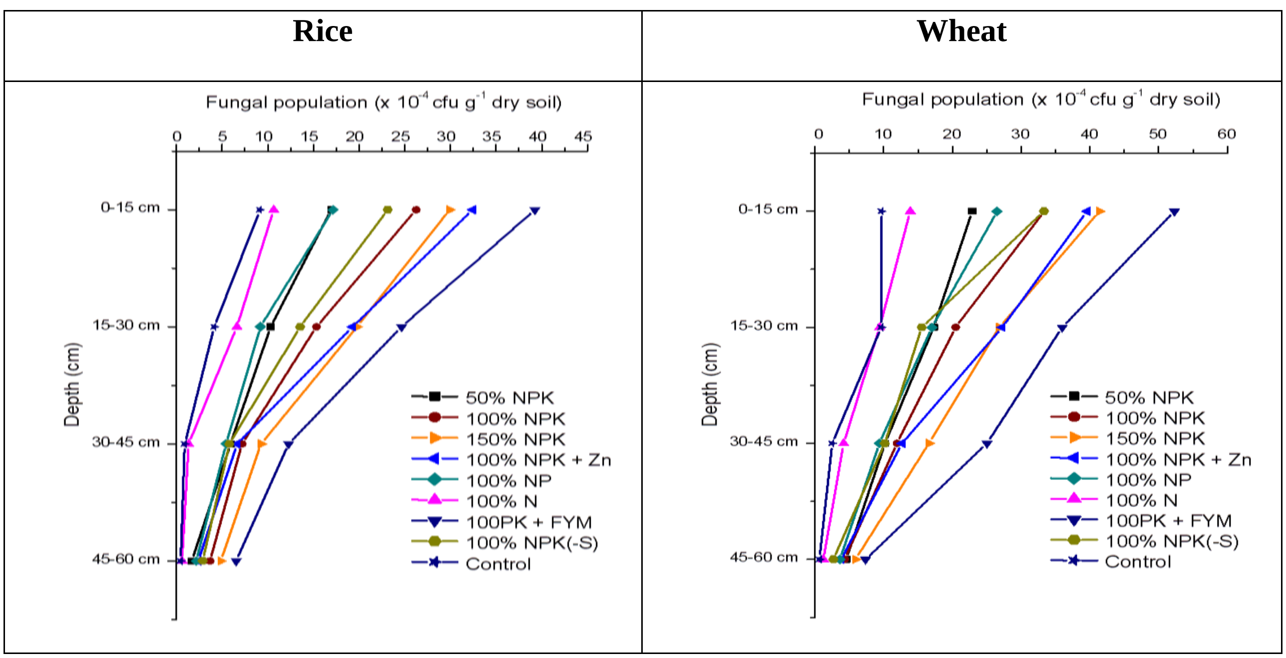
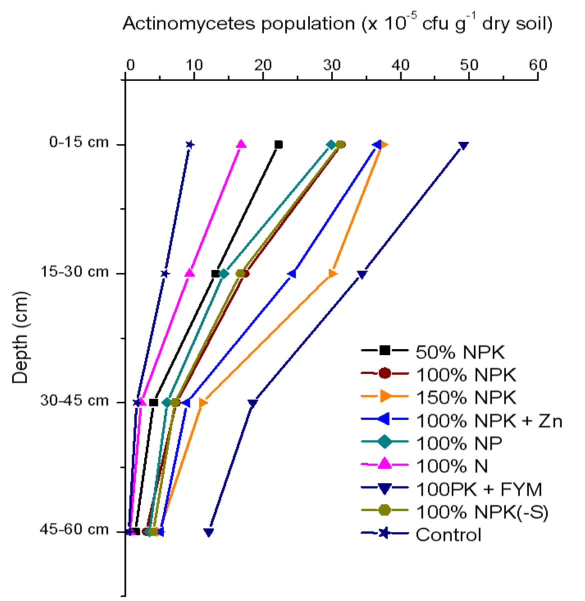
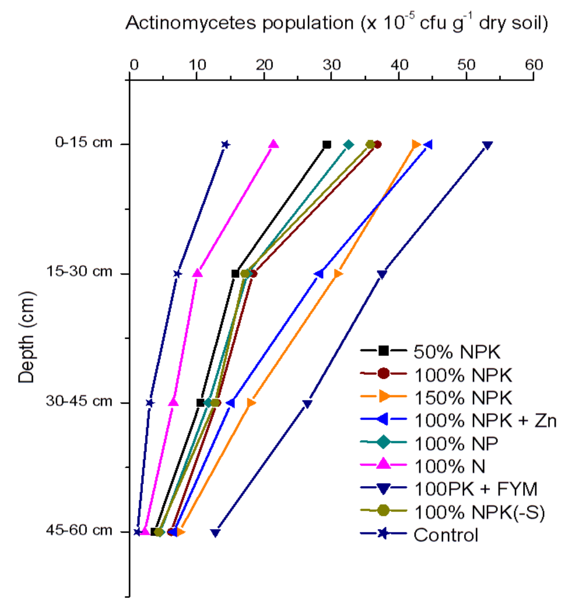


Figure.3 Effect of fertilizer application with different combinations of organic and inorganic sources on soil actinomycetes population ($\times 10^5$cfu g^{-1} dry soil)

Rice	Wheat
	

Soil microbial biomass carbon

Soil microbial biomass Carbon (SMBC) reflects the response of nutrient management on microbial biomass. The treatment with combination of organic and mineral source of nutrients registered the maximum (413.36 and 435.93 µg g^{-1} soil, respectively) and significantly higher content of SMBC in surface soil after harvest of both rice and wheat, sub-surface soil also showed same trend but the content of SMBC reduced in the deeper soil (Table 6). Treatment with 100% NPK in addition with FYM again showing the best result among all the treatment may be due to the catalytic effect of FYM in stimulating microbial growth, resulting in higher microbial biomass Vineela *et al.*, (2008) also reported significant enhancement in the soil microbial biomass C due to NPK and FYM application in Vertisols at Coimbatore. Treatments of 100% and 150% NPK were at par in soil microbial biomass C after wheat; however, a reduced dose of chemical fertilizers (50% NPK) resulted in significantly lower soil microbial biomass C than 100% NPK. Similarly, continuous use of 100% N, 100% NP and 100% NPK(-S) resulted in significantly low soil microbial biomass C than 100% NPK possibly due to inadequate and imbalanced supply of the nutrients for microbial utilization in soil. Minimum SMBC content was registered in control plot after both the crops.

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