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Influence of long-term application of organic and inorganic fertilizers on soil microbial properties

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***Abstract*— *A long-term field experiment was coducted during 2023–24 and 2024–25 at the Instructional Farm, Rajasthan College of Agriculture, Udaipur, to evaluate the effect of organic and inorganic nutrient management practices on soil microbial populations. The experiment was laid out in a randomized block design with twelve treatments comprising sole chemical fertilizers, organic manure, biofertilizers, and their integrated combinations. Soil microbial populations, including bacteria (cfu × 10^6), fungi (cfu × 10^4), and actinomycetes (cfu × 10^5), were analyzed and pooled data were used for interpretation. The results indicated that microbial populations were significantly influenced by different nutrient management treatments. Among all treatments, application of FYM @ 20 t ha^{-1} (T_8) recorded the highest pooled bacterial population (34.30 cfu × 10^6), fungal population (18.57 cfu × 10^4), and actinomycetes population (19.91 cfu × 10^5), followed by NPK + FYM @ 10 t ha^{-1} (T_7), which recorded pooled values of 31.71, 16.82, and 17.70, respectively. Integrated application of FYM 10 t ha^{-1} + 100% NPK (T_6) also resulted in higher microbial populations with pooled bacterial, fungal, and actinomycetes counts of 28.96, 16.35, and 17.38, respectively. In contrast, imbalanced fertilizer treatments such as 100% N (T_{11}) and control (T_{12}) recorded the lowest microbial populations, with pooled bacterial counts of 7.88 and 7.24, fungal counts of 7.43 and 5.52, and actinomycetes counts of 6.91 and 6.16, respectively. Pooled analysis confirmed that continuous application of FYM, either alone or in combination with chemical fertilizers, was most effective in enhancing soil microbial populations. The study highlights the importance of organic and integrated nutrient management practices in improving soil biological health and sustaining soil fertility.*

Keywords*— Soil microorganisms, bacteria, fungi, actinomycetes, integrated nutrient management, farmyard manure

I. INTRODUCTION

Soil microorganisms are integral components of the soil ecosystem and play a crucial role in nutrient cycling, organic matter decomposition, and maintenance of soil fertility. Microbial populations such as bacteria, fungi, and actinomycetes regulate biochemical transformations of carbon, nitrogen, phosphorus, and other essential nutrients, thereby influencing plant growth and soil productivity (Brady and Weil, 2017; Subbarao, 1999). Due to their rapid response to changes in soil management practices, soil microbial properties are widely used as sensitive indicators of soil health and sustainability. The long-term application of inorganic fertilizers has significantly contributed to increased agricultural production; however, continuous and imbalanced use of chemical fertilizers has been reported to adversely affect soil biological properties. Prolonged application of mineral fertilizers without organic inputs often leads to depletion of soil organic matter and reduction in microbial diversity and activity (Goyal et al., 1999). Such practices may suppress beneficial microbial populations and negatively impact soil biological functioning over time.

In contrast, organic amendments such as farmyard manure (FYM) supply organic carbon and essential nutrients that serve as energy sources for soil microorganisms, thereby enhancing microbial biomass and activity. Several studies have demonstrated that organic nutrient sources improve soil structure, moisture retention, and aeration, creating a favorable environment for microbial proliferation (Mäder et al., 2002). The addition of organic manures has also been shown to stimulate populations of bacteria, fungi, and actinomycetes, leading to improved nutrient availability and soil health. Long-term fertilizer experiments provide valuable information on the cumulative effects of nutrient management practices on soil biological properties. Integrated nutrient management, involving the combined use of organic manures and inorganic fertilizers, has been recognized as a sustainable approach for maintaining soil fertility and enhancing microbial activity (Yadav et al., 2017). Balanced fertilization ensures adequate nutrient supply to crops while minimizing the adverse impacts of sole chemical fertilizer application on soil biological processes. Different microbial groups respond differently to fertilization practices. Bacteria dominate in nutrient-rich environments and are primarily responsible for rapid nutrient mineralization, whereas fungi play an important role in decomposition of complex organic residues and soil aggregation. Actinomycetes contribute to the breakdown of resistant organic compounds and are particularly important in maintaining soil biological stability under long-term management practices (Subbarao, 1999; Brady and Weil, 2017). Therefore, understanding the influence of long-term application of organic and inorganic fertilizers on soil microbial properties is essential for developing sustainable nutrient management strategies. Such knowledge is critical for improving soil biological health, sustaining crop productivity, and ensuring long-term sustainability of intensive agricultural systems.

II. MATERIALS AND METHODS

Field Location and Experimental Site

The study was carried out under the All India Coordinated Research Project (AICRP) on Long-Term Fertilizer Experiment at a permanent experimental site (B2 block) located at the Instructional Farm of the Rajasthan College of Agriculture, Udaipur. The present investigation corresponds to the 26th and 27th maize–wheat cropping cycles of the long-term fertilizer experiment, which has been in continuous operation since *kharif* 1997. The experimental site is situated in the south-eastern region of Rajasthan at an elevation of 582.2 m above mean sea level and lies between 24°35′ N latitude and 73°42′ E longitude. The area falls within Agro-climatic Zone IVa, designated as the Sub-humid Southern Plain and Aravalli Hills region of Rajasthan.

Experimental Details

The field experiment was conducted during the *rabi* seasons of 2023–24 and 2024–25 using wheat (*Triticum aestivum* L.) variety Raj 4037 under a maize–wheat cropping system. A uniform seed rate of 100 kg ha^{-1} was used for all treatments. The experiment was laid out in a Randomized Block Design (RBD) with twelve treatments and four replications, comprising a total of 48 experimental plots. Each plot had a gross size of 20.0 m × 9.0 m (180 m^2) and a net plot size of 19.0 m × 8.0 m (152 m^2). Sowing was performed with a row spacing of 22.5 cm. All recommended agronomic practices, including irrigation scheduling, weed management, and plant protection measures, were uniformly adopted across all treatments in accordance with the regional package of practices for wheat cultivation.

Treatment Details

The experiment included twelve long-term nutrient management treatments consisting of organic manures, inorganic fertilizers, and their combinations, which have been applied continuously on the same experimental plots since 1997. The treatment details were as follows:

T_1: NPK
T_2: NPK + Zn
T_3: NPK + Zn + S
T_4: NPK + S
T_5: NPK + Bio
T_6: FYM 10 t ha^{-1} + 100% NPK (NPK adjusted for nutrients supplied through FYM)
T_7: NPK + FYM 10 t ha^{-1}
T_8: FYM 20 t ha^{-1}
T_9: 150% NPK
T_{10}: 100% NP
T_{11}: 100% N
T_{12}: Control (no fertilizer application)

III. ANALYSIS OF SOIL PARAMETERS

Soil Microbial Properties

Soil samples were collected from the surface soil layer (0–15 cm depth) after the harvest of wheat during both years of investigation. The collected samples were immediately brought to the laboratory and gently crushed by hand to break large clods, followed by removal of visible plant residues and stones. The soil samples were then passed through a 2-mm sieve and stored under refrigerated conditions until further analysis to preserve microbial activity.

The soil microbial populations were estimated using the serial dilution and plate count technique. Bacterial populations were enumerated using nutrient agar medium, fungi were estimated on potato dextrose agar medium, and actinomycetes were determined using actinomycetes isolation agar. Appropriate serial dilutions were prepared from each soil sample using sterile distilled water, and aliquots were plated on respective culture media under aseptic conditions. The inoculated plates were incubated at suitable temperatures for specific durations, after which the colonies were counted. Microbial populations were expressed as colony-forming units (cfu) per gram of soil, with bacterial counts expressed as cfu × 10^6 g^{-1} soil, fungal counts as cfu × 10^4 g^{-1} soil, and actinomycetes counts as cfu × 10^5 g^{-1} soil. Observations recorded for individual years were subjected to pooled analysis by averaging the data of both years to evaluate the long-term effects of organic, inorganic, and integrated nutrient management practices on soil microbial properties.

IV. RESULT AND DISCUSSION

It was evident from the data (Table 1 and Figure 1) that soil microbial populations were significantly influenced by the long-term application of organic and inorganic fertilizers under the maize–wheat cropping system. The pooled data revealed wide variation in bacterial, fungal, and actinomycetes populations across different nutrient management treatments, indicating differential responses of soil microorganisms to long-term fertilization practices. Among the treatments, application of FYM @ 20 t ha^{-1} (T_8) recorded the highest pooled microbial populations, with bacterial count of 34.30 cfu × 10^6 g^{-1} soil, fungal population of 18.57 cfu × 10^4 g^{-1} soil, and actinomycetes population of 19.91 cfu × 10^5 g^{-1} soil. This represented a substantial increase over the control treatment (T_{12}), which recorded the lowest microbial populations, with pooled bacterial, fungal, and actinomycetes counts of 7.24, 5.52, and 6.16 cfu × 10^5 g^{-1} soil, respectively. The pronounced improvement in microbial populations under T_8 clearly indicates the beneficial effect of continuous organic manure application on soil biological health. Integrated nutrient management treatments also resulted in significantly higher microbial populations compared to sole chemical fertilizer application. The treatment NPK + FYM @ 10 t ha^{-1} (T_7) recorded pooled bacterial, fungal, and actinomycetes populations of 31.71, 16.82, and 17.70 cfu × respective units, while FYM 10 t ha^{-1} + 100% NPK (T_6) registered corresponding values of 28.96, 16.35, and 17.38. These treatments remained statistically at par with FYM @ 20 t ha^{-1} and were markedly superior to treatments receiving only inorganic fertilizers. Balanced fertilization treatments involving micronutrients, sulphur, and biofertilizers showed moderate improvement in microbial populations, whereas imbalanced fertilization treatments such as 100% NP (T_{10}) and 100% N (T_{11}) recorded relatively lower microbial counts. The enhanced microbial populations under FYM and integrated treatments may be attributed to continuous supply of organic carbon and nutrients, which serve as energy sources for soil microorganisms and improve soil physical conditions such as aggregation, aeration, and moisture retention. The addition of organic matter also stimulates microbial proliferation by increasing substrate availability and promoting favorable microhabitats. In contrast, sole application of chemical fertilizers supplies nutrients without adding organic carbon, thereby limiting microbial growth under long-term intensive cropping. The observed findings are in close conformity with earlier studies, which reported that long-term application of organic manures, either alone or in combination with inorganic fertilizers, significantly enhances soil microbial populations and biological activity compared to exclusive use of chemical fertilizers (Goyal et al., 1999; Mäder et al., 2002; Yadav et al., 2017). Thus, the results clearly demonstrate that organic and integrated nutrient management practices are more effective in sustaining soil microbial properties and improving long-term soil health.

Table 1: Effect of organic and inorganic fertilization on bacterial, fungal and actinomycetes population of soil after harvest of wheat under wheat maize cropping sequence

Treatment	Bacteria (cfu x 10^6)			Fungi (cfu x 10^4)			Actinomycetes (cfu x 10^5)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: NPK	16.45	17.00	16.73	12.36	14.00	13.18	12.84	12.87	12.86
T_2: NPK + Zn	18.74	19.06	18.90	12.61	12.65	12.63	13.00	13.04	13.02
T_3: NPK + Zn + S	20.61	20.99	20.80	13.82	13.87	13.85	13.68	13.70	13.69
T_4: NPK + S	18.90	19.15	19.03	13.16	13.19	13.18	13.37	13.41	13.39

T5: NPK + Bio	23.72	30.00	26.86	12.29	12.31	12.30	12.91	12.95	12.93
T6: FYM 10 t + 100% NPK (- NPK of FYM)	28.79	29.13	28.96	16.33	16.36	16.35	17.35	17.40	17.38
T7: NPK + FYM 10 t ha^{-1}	31.44	31.98	31.71	16.80	16.84	16.82	17.68	17.71	17.70
T8: FYM 20 t ha^{-1}	33.96	34.64	34.30	18.55	18.59	18.57	19.85	19.97	19.91
T9: 150% NPK	19.08	19.72	19.40	14.49	14.51	14.50	14.80	14.83	14.82
T10: 100% NP	14.92	15.63	15.28	9.94	9.96	9.95	9.88	9.91	9.89
T11: 100% N	7.86	7.90	7.88	7.42	7.45	7.43	6.89	6.92	6.91
T12: Control	7.22	7.25	7.24	5.51	5.53	5.52	6.15	6.17	6.16
S.Em. ±	0.167	0.198	0.120	0.195	0.202	0.131	0.145	0.236	0.125
C.D. (P= 0.05)	0.481	0.571	0.338	0.562	0.580	0.370	0.418	0.679	0.354

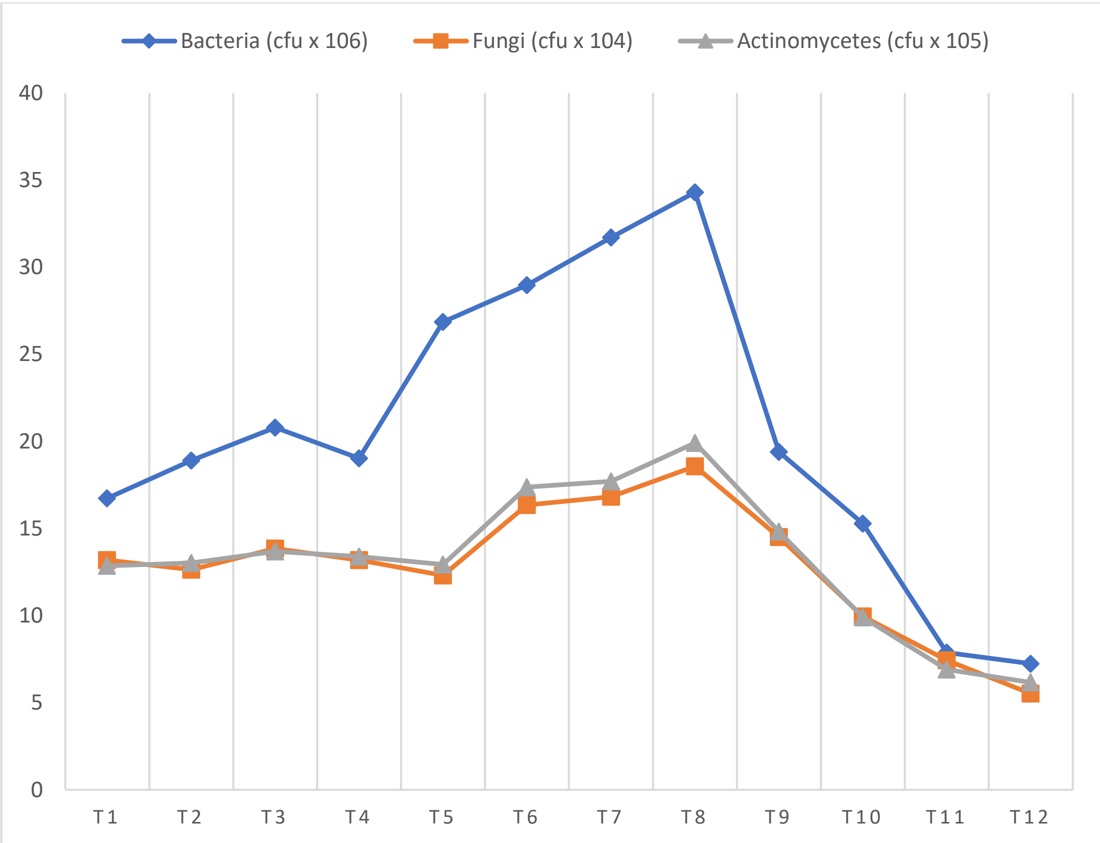

Fig.1: Effect of organic and inorganic fertilization on bacterial, fungal and actinomycetes population of soil after harvest of wheat under wheat maize cropping sequence

V. CONCLUSION

The results of the long-term fertilizer experiment clearly demonstrate that soil microbial properties were significantly influenced by different organic and inorganic nutrient management practices under the maize–wheat cropping system. Continuous application of farmyard manure (FYM), either alone or in combination with chemical fertilizers, proved to be most effective in enhancing soil microbial populations, including bacteria, fungi, and actinomycetes. The highest microbial counts were consistently recorded under FYM @ 20 t ha^{-1}, followed by integrated nutrient management treatments involving FYM and recommended NPK fertilizers, indicating the cumulative and beneficial effects of organic carbon inputs on soil biological health. In contrast, sole application of chemical fertilizers, particularly imbalanced treatments such as 100% N and 100% NP, resulted in comparatively lower microbial populations, reflecting their limited role in sustaining soil biological activity under long-term intensive cultivation. Balanced fertilization practices supplemented with micronutrients and biofertilizers showed moderate improvements but were inferior to organic and integrated approaches.

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