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Influence of various organic nutrient management technologies on microbial abundance, growth, and yield of rice (*Oryza sativa* L.) under field conditions

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ABSTRACT

A field study (three years) was carried out to evaluate the outcome of various organic nutrient management technologies including farmyard manure (FYM) and poultry manure (PM) integrated with chemical fertilizers for microbial dynamics and growth and yield of rice at Experimental Farm of Nuclear Institute of Agriculture (NIA), Tandojam, Sindh, Pakistan. The most broadly grown rice variety, NIA-Shandar was selected for this study. The experiment involved integrating organic technologies, specifically Farm Yard Manure (FYM) and Poultry Manure (PM), each applied at 10 tons per hectare. These organic technologies were combined with varying levels of inorganic fertilizers: half (60 kg N ha^{-1} and 45 kg P_2O_5 ha^{-1}) and full (120 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1}) recommended doses. Additionally, zinc was applied at 10 kg ha^{-1}. The study employed a randomized complete block design (RCBD) with three replications to assess treatment effects. Both organic technologies perform better for microbial dynamics and rice growth and yield enhancement either alone technology or combined with chemical fertilizers during three rice seasons. The maximum general microbial abundance (9.70 log_{10} CFU g $soil^{-1}$), N_2 fixing (7.37 log_{10} CFU g $soil^{-1}$), P solubilizing (7.97 log_{10} CFU g $soil^{-1}$) and Zn solubilizing (6.75 log10 CFU g $soil^{-1}$) population was recorded in FYM alone or with half N and P_2O_5 fertilizer application. The highest plant height (106 cm), tiller numbers (17.10), panicle numbers (26.53), panicle length (26.32 cm), one thousand grain weight (26.53 g) and rice grain yield (7.92 t ha^{-1}) were perceived in FYM with full rate N and P_2O_5 fertilizer application. Both technologies along with chemical fertilizer induced soil properties and soil nutrients which reflected to increase soil microbial abundance and growth and yield of rice however, FYM showed higher potential than poultry manure during the three years rice cultivation seasons. Hence, it was indicated that a significant contribution to the development of sustainable agricultural technologies that prioritize soil health, environmental stewardship, and food security.

1. Introduction

Rice is a vital crop in agriculture, playing a significant role in food security, ensuring food availability and accessibility for over half of the global population, providing sustenance for the people. It is contributing to improve soil health, water management, biodiversity, and climate resilience through crop rotation, organic matter addition, and soil moisture management. The excess utilization of mineral fertilizers, particularly N to get maximum crop yield mostly leads to problems in soil such as soil degradation and nitrate leaching, which, affects the soil fertility and lessens crop yield [1]. Improving the input efficiency in crop production systems, predominantly relying on organic sources has significant potential not only to reduce dependence on mineral fertilizers but also to boost crop efficiency and sustainability. Utilizing livestock waste materials with minimized mineral fertilizers through soil application in low-input agricultural farming has been extensively documented as a dynamic agricultural technology for enhancing soil fertility [2]. Furthermore, the integrated use of fertilizers (organic and inorganic) could increase soil pH, soil fertility and soil microbial community [1]. The consumption of chemical fertilizers with various organic sources are a valuable technology for enhancing the nutrients crucial for growth of plants and can be safely applied to soil, crops, and suitable for the environment [3].

Rice holds a prominent position among global cereal crops and plays a decisive part in the agricultural economy. With the world population experiencing rapid growth, meeting the global demand for rice necessitates the application of fertilizers to ensure optimal growth and productivity [4]. In Pakistan, rice holds the third position among major crops, following wheat and cotton, cultivated on approximately 11% of the country's total agricultural land [5]. Pakistan distinguishes itself as a leading producer and exporter of rice. Moreover, rice contributes 3.1% to the value addition in the agricultural sector and constitutes 0.6% of the GDP. During 2019-20 cropped area of 3,034 m ha^{-1} increased by 8.0 % compared to 2,810 t ha^{-1} of last year. The production increased by 2.9 % to 7.41 million tonnes against 7.202 million tonnes [6].

Nevertheless, surplus N which has not been taken by plants reacts with the soil to produce the hazardous greenhouse gases. Similarly, non-judicious use of P fertilizer may create several environmental issues [7]. Worldwide agriculture sector accounts for 80% of human caused N_2O emissions and totally 8 to14% of all greenhouse gases. The CO_2 is lost from the soil due to organic matter decomposition and erosion and recovery is to be required [8]. Hence, researchers are emphasizing the exploration of alternative or supplementary options to chemical fertilizers for ensuring food security in an effective manner. Use of organic fertilizers with minimum use of inorganic fertilizers is a feasible approach to mend soil fertility and efficiency along with mitigating soil degradation [9]. Amongst the organic modification, FYM and PM have been commonly used in agricultural fields to mitigate the risk of nitrogen loss through leaching and surface runoff, upsurge soil organic matter, and reduce greenhouse gas emissions [8]. The integrated use of chemical fertilizers with FYM significantly enhances soil organic matter (SOM), total nitrogen content, and soil microbial biomass [10]. Soil microorganisms play a crucial role in agriculture by establishing close connections with plants, thereby improving soil health and fostering plant development [11]. Earlier research findings indicated that incorporating livestock waste materials, either independently or in conjunction with inorganic fertilizers, heightened enzymatic-activities and microbial diversity in the soil [12].

Additionally, microorganisms perform a crucial role in improving nutrient availability by atmospheric N_2-fixation and P-solubilization from insoluble sources in soil and improve plant growth by phytohormones production [13]. Moreover, the maximum productivity carried out by applying chemical fertilization in the agricultural systems that emphasize the contributions of organic resources in the practice of root exudates, decomposing roots, and on the ground deposits, and consequently, enhances the pool of C source for soil microbial communities [14]. The continuous use of NPK chemical fertilizers causes a substantial reduction of microbial diversity, whereas additions of organic manures restore bacterial diversity and improve soil health [10]. Soil microorganisms play pivotal roles in maintaining soil health, including the decomposition of organic matter, nutrient cycling, and ecosystem stabilization, which are essential processes sustaining terrestrial ecosystems. Specifically, soil microbial biomass, community composition, and physiological functions are sensitive to above ground vegetation and below ground circumstances [15].

An ideal indicator of soil quality, encompassing chemical, physical, and biological properties, should exhibit sensitivity to management-induced changes, ease of measurement, relevance across diverse sites and timeframes, cost-effectiveness, strong correlation with desired outcomes, and adaptability to specific ecosystems. Combined use of organic manures and chemical (NPK) fertilization, not only increase SOC, soil nutrients and total nitrogen but also enhance the bacterial community for better crop production [16]. The farmyard manure (FYM) represented a promising approach to maintain sustainable nutrient supply for crop growth. The FYM could possibly be provided to the soil in a form which is readily available to plants and soil microorganisms [17]. The treatments comprised a control group and a group with a recommended dose of chemical fertilizer, a group with five (5) tons per hectare of chicken manure, and a group with 2.5 tons per hectare of chicken manure with recommended dose of chemical fertilizer. It was observed that the effect of chicken manure with chemical fertilizer on rice growth and yield was significantly positive [18]. The findings of the study were combined application of chicken manure and chemical fertilizer enhanced rice yield and sustainability. Furthermore, the highest grain yield was detected in the treatment with the joint use of chicken manure and chemical fertilizer, with an upsurge of up to 12% associated to the control group [19].

The soils are mostly low in organic matter and low in nutrients so there is a dire need to supplement such type of organic sources which can improve soil health and nutrients availability for the better crop production. Therefore, the study aimed to determine the interactive outcome of organic adjustments and mineral fertilizers on soil microbial-abundance and assess the growth and yield enhancement of rice under combined use of organic technologies and mineral fertilizers in field environments of Tandojam.

2. Materials and Methods

2.1 Study-Site and Experimental Design

The experiment (three years) was designed at the experimental field of Nuclear Institute of Agriculture (NIA), Tandojam, Sindh, Pakistan, five meter above the level of sea, situated at the Latitude of 25°25′35.68″N and Longitude of 68°32′22.31″E. Two (2) organic sources poultry manure and farm yard manure were used (10 t ha^{-1}) respectively. However, the recommended dose of chemical fertilizers N as urea and P_2O_5 as triple super phosphate were applied at full (120 and 90 kg ha^{-1}) and half (60 and 45 kg ha^{-1}) rates with and without organic sources. The Zn as $ZnSO_4$ was applied at 10 kg ha^{-1} in the treatments. The 25 days old seedlings of rice genotype (NIA-Shandar) were transplanted (20×20 cm) in each plot (4m × 4m). The study was conducted for three years, where organic sources were applied for two years and one year was kept as residual. The experimental setup utilized a Factorial Randomized Complete Block Design with 03 replications.

2.2 Soil Analysis

Soil samples were collected to assess soil physio-chemical properties, soil organic matter (SOM) content, and soil nutrient composition. The soil texture was determined using the Bouyoucos-hydrometer technique followed by Gee, and J.W. Bauder method [20], while organic matter content was assessed according to the Walkley and Black method [21]. The soil organic carbon (SOC) was calculated (formula: SOC% = SOM/1.724×100). EC was observed with a digital EC meter at a soil-water (1:2.5) ratio using by Jones [22] method. Soil pH was determined at 30°C using pH meter (PHM210) using by Jones [22] method. Total nitrogen (N) was quantified using the Kjeldahl-digestion technique [23], and AB-DTPA Ex. P and K were analyzed by the method of Soultanpur, and Schwab [24].

2.3 Physio-Chemical Soil Properties and Nutrient Composition of Organic Sources

The soil was clay loam in texture, slightly saline (1.24 dS m^{-1}) with neutral in soil pH. However, soil was low in OM (0.67%), OC (0.303%) and N (0.05%) and medium in P (6.11 mg kg^{-1}), with adequate (127 mg kg^{-1}) in K (Table 1). The farm yard manure was alkaline (pH 8.10) in nature, non-saline with 10.71% of OC and containing N, P and K, 0.53, 0.23 and 0.59 % respectively (Table 2). Conversely, poultry manure was neutral in pH, including EC (0.33 dS m^{-1}). The poultry manure contained higher OC (14.11%), N (2.20%), P (1.60 %) and K (1.35 %) than the farm yard manure (Table 2). The average (three years) maximum temperature during the experimental period was 42.3 °C in the month of June and minimum was 25.8 °C in month of October. The highest humidity 59% was in month of August and lowest (34%) was in month of October. The maximum average precipitation (60.78 mm) was in the month of August and minimum was noticed in the month of October during the period. However, the maximum sunshine 12.1 hr was in month of June and minimum was in October month 8.6 hr during the planting period (Table 3).

Table 1

Soil physical and chemical characteristics

Soil Texture	EC (1:2.5)	pH	*OM	*OC	N	P	K
	---- (dS m^{-1}) ----		-------------------- (%) -------------------			---- (mg kg^{-1}) ----	
Clay Loam	1.24	7.1	0.67	0.303	0.05	6.11	127

*OM= organic matter, *OC= organic carbon

Table 2

Nutrient composition of farmyard manure (FYM) and Poultry manure (PM)

Organic sources	pH	EC 1:10 (dS m^{-1})	*OC	N	P	K
			---------- (%) ----------			
FYM	8.10	0.13	10.71	0.53	0.23	0.59
PM	7.23	0.33	14.11	2.20	1.60	1.35

*OC= organic carbon

Table 3

Average (three years) weather report of the experimental area

Months		June	July	Aug	Sep	Oct
Temp (°C)	Min	29.8	29.3	28.3	27.2	25.8
	Max	42.3	39.3	37.4	38	38.2
Humidity	(%)	47	56	59	53	34
Rainfall	(mm)	12.56	57.45	60.78	22.04	0
Sunshine	(hr)	12.1	11.5	10.1	9.6	8.6

2.4 Bacterial Observations

The rhizospheric rice root samples were gathered randomly from the various experimental treatments after 60 days of transplanting and carried in an ice box and kept at 40ºC temperature before analyses at Microbiology laboratory, Nuclear Institute of Agriculture (NIA), Tandojam for the different bacterial observations.

2.5 Enumeration of Total Microbial Population

The overall microbial population in the rhizosphere of rice plants was examined at 45 days post-transplantation on specific agars. Nutrient agar media plates were employed for computing the total microbial population (CFU). Nfb media plates were utilized for N2-fixing bacteria [25]. In addition, the inhabitants of phosphate solubilizing bacteria was evaluated using Pikovskaya media [26], and the population of zinc-solubilizing bacteria was observed using Bunt and Rovira agar, consisting of glucose (10.0 g), NH_4-sulfate (1.0 g), K-chloride (0.2 g), dipotassium hydrogen phosphate (0.1 g), Mg- sulfate (0.2 g), and 0.1% insoluble zinc compound ($ZnCO_3$) in distilled water (1000 ml) at pH 7.0 [27]. Approximately ten grams of rhizospheric soil were placed in Erlenmeyer flasks (250 mL) comprising 90mL of sanitized water. The flasks underwent agitation to attain a uniform mixture over a period of 15 to 20 minutes using a mechanical shaker. Dilutions ranging from 10^{-1} to 10^{-8} were formulated, and 0.1 ml portions were deposited onto specific agar plates. Subsequently, the plates were placed in an incubator at 28±2 °C for duration of three days. Colony-forming unit (CFU) counts were determined through the utilization of a colony counter, correlating bacterial population with both dilution factors and the volume of aliquot plated. Microbial strains exhibiting diverse colony morphologies were chosen from the agar plates, and the pureness of bacterial strains was verified by microscopic examination of their morphological characteristics.

2.6 Agronomical Observations and Nutrient Concentration in Rice Plant

The rice plants reached maturity, and their growth traits and yield were documented after harvesting from a one-square-meter area for each treatment. Parameters such as plant height, root length, number of tillers, number of panicles, panicle length, 1000-grain weight, grain yield, and straw yield were calculated at the time of harvest. Plant samples underwent a washing process to eliminate the soil debris and were then oven dried (at 70°C) for three days to determine plant dry biomass. The plant nutrient uptake was determined by wet digestion method using 1:5 perchloric and nitric acid ($HClO_4$:HNO_3) mixture. Wet digestion was performed on the finely crushed and dried [28]. Total N in soil was taken using Kjeldahl's method [23]. Total P and K were determined by using by Ryan et al. [29] method.

The calculation of plant nutrient uptake involved multiplying the plant dry weight by the nutrient concentration [28: 24]. However, the percentage of grain protein was determined by Jones's factor N × 5.95 (1/0.16 = 6.25) to transform nitrogen into protein content [30].

2.7 Statistical Analysis

All the experimental data were statistically evaluated via analysis of variance and treatment means were compared using Tukey's test (at 5%) level of confidence [31].

3. Results and Discussion

Three year field study on rice genotype (NIA-Shandar) was piloted at Experimental Farm at Nuclear Institute of Agriculture (NIA) Tandojam, Sindh, Pakistan. The soil was neutral (pH 7.1) and slightly saline (1.24 dS m^{-1}). The soil organic matter content (0.67%) was low. The soil of experimental site was low in N, while medium in AB-DTPA Ex.-P and K. The utilization of chemical fertilizers, organic manures, and their combinations has demonstrated noteworthy impacts on the sustainable production of crops, constituting a crucial element in diverse agricultural systems. [32].

3.1 Interactive Effect of Organic Sources and Chemical Fertilizers on Total Microbial Abundance

The interactive effect of different organic sources and chemical fertilizers on total bacterial abundance affected the soil total bacterial abundance during the three years rice planting period (Fig. 1). The total abundance was greater in the organic sources applied likened to alone chemical fertilizer application. However, significantly ($P<0.05$) the highest abundance (9.70 $\log_{10}$ CFU g soil-1) was found in FYM followed by PM (9.69 $\log_{10}$ CFU g $soil^{-1}$) in the year 3 planting period. The bacterial abundance was exposed slightly increasing trend with the passage of time from year 1 to year 3 continuously in both organic sources treatments while decrease was shown in the chemical fertilizer applications.

The study unveiled the abundance of soil rhizospheric microbes during the crop cultivation however, the higher abundance was noted in organic sources applied particularly in the treatment where FYM was applied with chemical fertilizers. The soil rhizosphere is the well-known portion of soil where organic matter is accessible by rhizodeposition that has been reported to enhance soil microbial activity [33].

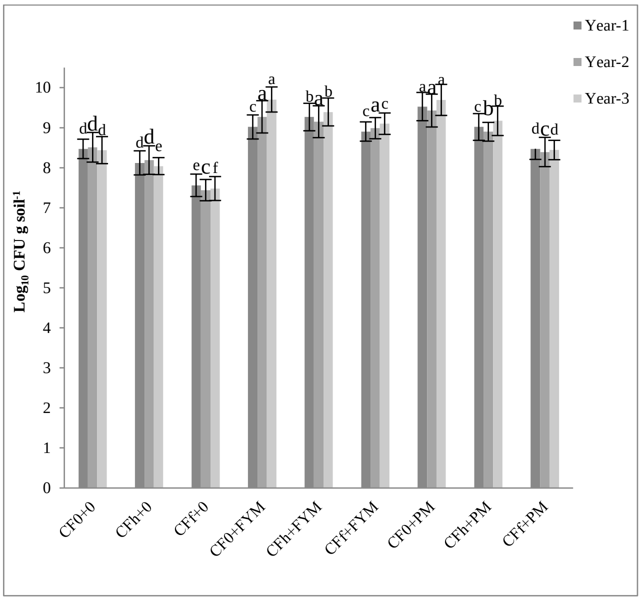

Fig. 1. Interactive Effect of Organic Sources and Chemical Fertilizers on Total Microbial Abundance

CF=chemical fertilizer, CFh=chemical fertilizer half rate, CFf=chemical fertilizer full rate, FYM=farmyard manure, PM= poultry manure. Means within the same column followed by the same letters are not significantly different at $P>0.05$.

3.2 Interactive Effect of Organic Sources and Chemical Fertilizers on Nitrogen (N_2) Fixing Bacterial Population

The experimental plot showed the presence of nitrogen (N_2) fixing bacteria in all treatments. The application of various organic sources with and without chemical fertilizers affected the soil N_2 fixing bacteria during the rice planting period (Fig. 2). The N_2 fixing bacterial isolates were existing higher in population particularly in organic treatments compared to chemical fertilizer application. Nevertheless, significantly ($P<0.05$) the highest population (7.37 log10 CFU g $soil^{-1}$) was reported in FYM alone followed by (7.28 log10 CFU g $soil^{-1}$) FYM with full rate of chemical fertilizer. However, population was showing decrease with the chemical fertilizers either alone or with organic sources. Addition of organic sources enhanced the nitrogen fixers during the planting period. Current three years study shows the maximum N_2 fixing bacterial population in all rice treatments which shows their existence in soil rhizosphere. However, both organic sources (FYM and PM) during the crop growth period enhanced bacterial population either applied alone or with chemical fertilizer [34].

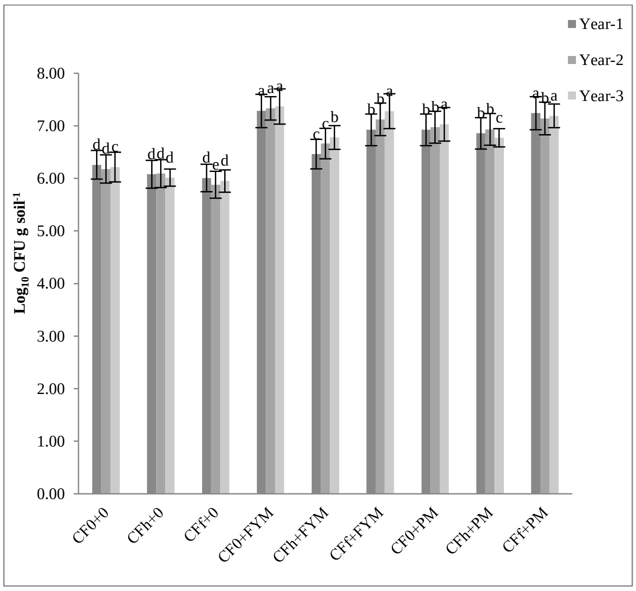

Fig. 2. Interactive Effect of Organic Sources and Chemical Fertilizers on N_2 Fixing Bacterial Population in Rice Crop

CF=chemical fertilizer, CFh=chemical fertilizer half rate, CFf=chemical fertilizer full rate, FYM=farmyard manure, PM= poultry manure. Means within the same column followed by the same letters are not significantly different at P>0.05.

3.3 Interactive Effect of Organic Sources and Chemical Fertilizers on P-Solubilizing Bacterial Population

The interactive effect of various organic sources and chemical fertilizers affected the phosphate solubilizing bacterial population. However, the application of different organic sources with and without mineral fertilizers exaggerated the phosphate solubilizing bacterial population during the rice crop planting period (Fig. 3). A similar trend was observed in phosphate solubilizing bacterial strains that organic sources applied treatments were showing higher population than the chemical fertilizer treatments. Significantly (P<0.05) the highest population (7.97 log$_{10}$ CFU g soil^{-1}) was reported in FYM alone followed (7.65 log10 CFU g soil^{-1}) by FYM either at half or full mineral fertilizer. However, a decrease trend was shown in chemical fertilizer alone treatment with the planting period.

The current study shows the maximum P-solubilizes in all rice treatments which shows their existence in soil rhizosphere. Nevertheless, organic sources (FYM and PM) during the crop growth period improved P-solubilizing bacteria with or without chemical fertilizer. These microbes varied among the various organic contents and soil physical and chemical properties [33, 34].

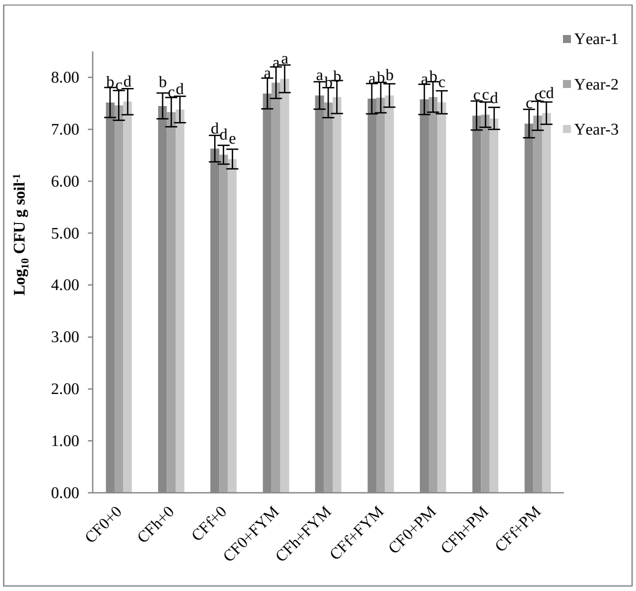

Fig. 3. Interactive Effect of Organic Sources and Chemical Fertilizers on P-Solubilizing Bacterial Population in Rice Crop

CF=chemical fertilizer, CFh=chemical fertilizer half rate, CFf=chemical fertilizer full rate, FYM=farm yard manure, PM= poultry manure. Means within the same column followed by the same letters are not significantly different at P>0.05.

3.4 Interactive Effect of Organic Sources and Chemical Fertilizers on Zn Solubilizing Bacterial Population

The interactive influence of organic sources with chemical fertilizers effected the zinc bacterial population in rice field experiments. However, the organic sources applied treatments were showing higher population than the chemical fertilizer treatments. In addition, an increasing trend of bacterial population was observed in the organic sources, in contrast a declining tendency was detected in the chemical fertilizer applied treatments during the various rice planting seasons (Fig. 4). Significantly (P<0.05) the highest bacterial population (6.75 log$_{10}$ CFU g soil^{-1}) was found in FYM alone (6.38 log$_{10}$ CFU g soil^{-1}) followed by FYM either at half or full chemical fertilizer. Surprisingly, lower zinc solubilizing bacterial population was perceived in PM alone. Nonetheless, a decrease trend was shown in mineral fertilizer alone during the planting period. An increasing trend was shown in both organic sources and decreasing trend in population was observed in chemical fertilizer treatments during the planting seasons. The current research proved the presence of Zn-solubilizing bacterial strains in soil rhizosphere during the cultivation period. On the other hand, these microbes were varied among the various organic sources (FYM and PM) during the study period which may be due to soil organic contents in soil and various rates of chemical fertilizer applications [33, 34].

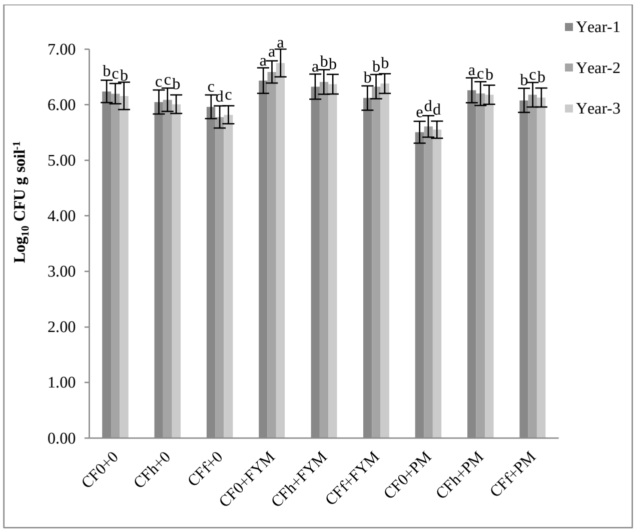

Fig. 4. Interactive Effect of Organic Sources and Chemical Fertilizers on Zn Solubilizing Bacterial Population in Rice Crop

CF=chemical fertilizer, CFh=chemical fertilizer half rate, CFf=chemical fertilizer full rate, FYM=farm yard manure, PM= poultry manure. Means within the same column followed by the same letters are not significantly different at P>0.05.

In addition, the current study revealed an increasing trend for bacterial abundance with organic nutrient sources however, a decrease in bacterial population was observed where chemical fertilizers were given alone during the cultivation seasons. The increase of beneficial microbes such as N_2 fixing, P and Zn solubilizing bacterial population was positively correlated with the adding of organic sources. Alike consequences were conveyed from the earlier studies that the increase of bacterial population was observed as a result of organic amendment in the soil, including FYM and PM application into the soil [16, 17]. The total microbial abundance was significantly (P <0.05) in relation with the variation in soil total C and total N. The differences in bacterial population can be correlated with the soil health and fertility or soil stabilization [34]. It can also be an indicator of the organic status of the soil. Moreover, the presence of microbes and their activity in soil play an important role for the soil fertility and of plant beneficial activities particularly for soil nutrient mobilization and plant growth enhancement [35, 36].

3.5 Interactive Effect of Organic Sources and Chemical Fertilizers on Rice Growth Parameters

Interactive effect of organic sources and chemical fertilizers affected the rice plant height during the different planting years. The organic sources applied treatments with chemical fertilizers showed maximum growth compared to chemical fertilizers alone application. The significantly (P<0.05) the maximum plant height 106.07 cm and 95.8 cm was observed in PM with full chemical fertilizer application for year 1 and year 2 respectively (Table 4). However, in year 3 maximum plant height (95.6 cm) was found in FYM with chemical fertilizer at full rate of application whereas, lowest plant height was recorded in control treatments during the planting period.

The organic sources and chemical fertilizers exaggerated the number of tillers of rice plants during the different planting years. The organic sources applied treatments with chemical fertilizers exposed the maximum number of tillers associated to chemical fertilizers alone application. Significantly (P<0.05) the maximum number of tillers 16.11 plant^{-1} followed by 16.01 number of tillers plant^{-1} were observed in PM with full and half chemical fertilizer treatments for year 1 respectively (Table 4). However, in year 2 and year 3 maximum tillers 23.1 and 17.10 plant^{-1} were found in FYM with full rate of chemical fertilizer application whereas, lowest tillers were recorded in control treatments during the planting period respectively.

The interactive effect on organic sources and chemical fertilizers exaggerated the number of panicles of rice plants during the various planting years. The organic sources applied treatments with chemical fertilizers exposed the maximum number of panicles associated to chemical fertilizers alone application. The significantly (P<0.05) the maximum number of panicles 26.53 followed by 26.27 plant^{-1} were observed in PM with full and half chemical fertilizer treatments for year 1 respectively (Table 4). However, in year 2 and year 3 maximum number of panicles 21.43 and 15.46 plant^{-1} were found in FYM with full rate of chemical fertilizer application whereas, lowest panicles numbers were observed in control treatments during the planting period.

The interactive effect on organic sources and chemical fertilizers affected panicle length of rice plants during the planting years. The organic sources applied treatments with chemical fertilizers showed the maximum length of panicles associated to chemical fertilizers alone application. Significantly (P<0.05) the maximum panicle length (25.73 cm) followed by 23.72 plant^{-1} were observed in PM and FYM with full chemical fertilizer treatments for year 1 respectively (Table 4). However, in year 2 and year 3 the maximum number of panicles 26.32 and 24.65

plant-1 were found in FYM with full rate of chemical fertilizer application whereas, lowest panicles numbers were observed in control treatments during the planting period.

Interactive influence of organic sources and chemical fertilizers affected the plant growth parameters during the rice planting period. The combination of organic nutrient sources with chemical fertilizers resulted in maximum crop growth including plant height, number of tillers, number and size of panicles as compared to chemical fertilizers alone treatments. In the same way, the previous research showed that various organic sources applied with beneficial microbes and chemical fertilizers enhanced rice growth promoting traits such as panicle numbers, panicle length, number of filled grain, 1000 grain weight and rice yield. However, the treatment of organic nutrient source with 25% reduced chemical fertilizer showed at par result with 100 % chemical fertilizer applied treatments [37].

3.6 Interactive Effect of Organic Sources and Mineral Fertilizers on Rice Yield

The organic sources and chemical fertilizers affected grain weight of rice plants during the planting years. The organic sources applied treatments with chemical fertilizers showed the maximum 1000 grains weight linked to chemical fertilizers alone application. The significantly ($P<0.05$) the highest 1000 grain weight (26.01 g) followed by (25.91 g) PM with full and half chemical fertilizer treatments for year 1 respectively (Table 5). Whereas, in year 2 and year 3 the maximum 1000 grain weight 26.53 g and 24.44 g were observed in FYM at full rate of chemical fertilizer application whereas, lowest grain weight was found in control treatments during the planting period.

The organic sources and chemical fertilizers affected rice yield during the planting years. The organic sources applied treatments with chemical fertilizers exhibited the highest rice yield likened to chemical fertilizers alone application. Significantly ($P<0.05$) the utmost straw yield (14.82 t ha^{-1}) and grain yield (7.92 t ha^{-1}) were recorded in PM with full chemical fertilizer treatments for year 1 (Table 5).

Whereas, in year 2 and year 3 the maximum grain and straw yield 7.25 and 7.67 t ha^{-1} were documented in FYM with full rate of chemical fertilizer application whereas, lowest grain weight was found in control treatments during the planting period respectively.

The organic sources and chemical fertilizers affected rice harvest index during the planting years. The organic sources applied treatments with chemical fertilizers showed the maximum rice harvest index associated to chemical fertilizers alone application. Significantly ($P<0.05$) the highest harvest index (56.8 %) was found in PM alone applied treatments for year 1, whereas, during year 2 the maximum harvest index (62.6 %) was observed in chemical fertilizer at half rate of chemical fertilizer application whereas, in year 3 the maximum index (64.4%) was recorded in FYM applied alone treatments (Table 5).

The organic sources integrated with chemical fertilizer exaggerated the rice yield parameters during the rice three years planting period. The organic sources applied treatments with chemical fertilizers enhanced the grain and straw weight as related to use of chemical fertilizers alone application. It might be due to the organic biomasss which was a possible source of nutrients for rice and resulted significantly increasing in growth and yield of rice [38].

The increase in rice crop yield might be due to supplying maximum nutrients in the soil and that influence the yield parameters such as dry biomass, panicle length, 1000 grain weight and maximum filled grains per panicle. Similar reports were published by Sharma et al. [39] that applying organic sources (Green manure with organic based biofertilizer) which indorses in leaf photosynthesis, biomass production and sink formation, that directly resulting in enhancing the grain yield of rice. The organic sources improved soil microbes which directly increased P-solubilizing activity, PSB releases growth hormone (IAA) that might have prejudiced on rice growth and yield. In addition, wide root system might have improved plant nutrient uptake that influenced plant biomass and consequently higher rice grain yield. These results were consistent with Panhwar's et al. [40] findings.

Table 4

Interactive effect of organic sources and mineral fertilizers on rice growth parameters

Treatments	Plant height (cm)			No. of tillers plant^{-1}			No. of panicles plant^{-1}			Panicle length (cm)		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
CF0+0	95.27d	82.2f	74.4f	11.27d	12.4e	10.20d	23.00d	12.00e	9.62d	18.10e	19.12e	17.23d
CFh+0	101.13c	86.6d	79.4d	11.73d	15.8d	12.80b	24.47c	13.07e	10.83c	19.90c	20.08d	18.52c

CFf+0	102.60c	91.4c	83.0c	15.64b	19.3c	13.20b	25.07b	18.01c	13.02b	20.76c	22.25c	22.17b
CF0+FYM	97.07d	84.4e	80.4d	11.89d	12.6e	12.40c	24.07c	15.20d	12.06c	18.86d	20.10d	22.16b
CFh+FYM	104.60b	96.2a	89.8b	14.97c	20.4b	16.20a	25.13b	19.22b	14.42a	20.25c	23.25b	24.24a
CFF+FYM	105.80b	94.0a	95.6a	15.83b	23.1a	17.10a	25.67b	21.43a	15.46a	23.72b	26.32a	24.65a
CF0+PM	102.07c	85.2d	77.2e	11.98d	13.4e	11.00d	24.00c	12.21e	11.86c	19.56c	0.15d	19.06c
CFh+PM	105.97b	89.4c	83.4c	16.01a	19.2c	12.13c	26.27a	18.42b	12.11c	22.84b	2.18c	23.76a
CFF+PM	106.07a	95.8a	88.8b	16.11a	21.2b	14.80b	26.53a	19.81b	13.57b	25.73a	24.11b	23.87a

* CF=chemical fertilizer, FYM=farmyard manure, PM= poultry manure. Means within the same column followed by the same letters are not significantly different at P>0.05

Table 5

Interactive effect of organic sources and mineral fertilizers on rice yield

Treatments	Weight of 1000 grains (g)			Rice straw yield (t ha^{-1})			Rice grain yield (t ha^{-1})			Harvest index (%)		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
CF0+0	17.29f	20.33e	19.65e	6.96f	5.03f	6.16f	3.29d	2.09f	2.96e	47.3d	41.6e	48.1d
CFh+0	21.76d	21.56d	20.32d	10.72d	7.59e	9.58c	5.17c	4.75d	4.22d	48.2c	62.6a	44.1e
CFf+0	23.75c	22.38c	22.08c	11.89bc	10.64c	10.02c	6.18b	5.07c	5.83c	52.0b	47.7d	58.2b
CF0+FYM	20.01e	21.68d	22.23c	9.38e	9.64d	8.42d	5.07c	4.28d	5.42c	54.1a	44.4d	64.4a
CFh+FYM	22.41d	24.03b	23.01b	11.62c	11.98b	12.82b	6.26b	7.23a	6.83b	3.9ab	60.3b	53.3c
CFF+FYM	24.12b	26.53a	24.44a	12.51b	13.34a	13.87a	6.34b	7.25a	7.67a	50.7b	54.3c	55.3b
CF0+PM	21.16d	21.00d	20.68d	10.67d	9.49d	7.87e	6.06b	3.82e	4.67d	56.8a	40.3e	59.3b
CFh+PM	25.91a	22.62c	21.73d	14.41a	11.65b	12.38b	7.14a	5.67c	6.18b	49.5c	.48.7d	49.9d
CFF+PM	26.01a	24.45b	23.62b	14.82a	12.29b	12.03b	7.92a	6.60b	6.62b	53.4b	53.7c	55.5b

* CF=chemical fertilizer, FYM=farm yard manure, PM= poultry manure. Means within the same column followed by the same letters are not significantly different

3.7 Interactive Effect of Organic Sources and Mineral Fertilizers on Nutrient Concentration in Rice Soil

The organic sources and chemical fertilizers with or without chemical fertilizer increased nutrient concentration during the planting years. The organic sources applied treatments with chemical fertilizers showed the higher concentration in soil compared to chemical fertilizers alone application. Significantly (P<0.05) the utmost N (0.0272%), was found in PM with full rate of chemical fertilizer during the year 1 whereas, during year 2 and year 3 the maximum N 0.0253 % and 0.0300 % was observed in PM and FYM with full chemical fertilizer application respectively (Table 6).

The significantly (*P*<0.05) the maximum P (15.38 ppm) was found in PM followed by (14.74 ppm) in PM at full rate of chemical fertilizer during the year 1 whereas, in year 2 and year 3 the maximum P 18.61 ppm and 18.87 ppm was noticed in FYM with full chemical fertilizer applied treatments respectively. In case of K the significantly (P<0.05) the highest concentration was 228 ppm and 240 ppm recorded in PM at full chemical fertilizer application during year 1 and year 2 while during the year 3 the maximum 263 ppm of K was recorded in FYM with full chemical fertilizer applied treatments (Table 6).

The application of organic sources with chemical fertilizers enhanced the nutrient concentration in soil. Generally, addition of organic nutrient sources with chemical fertilizers increased the nutrient concentration in soil compared to chemical fertilizers alone application. Das et al. [41] noted that mineral fertilizer combined with FYM (cattle manure) significantly ($p < 0.05$) enhanced organic matter, total N content and soil biomass C in the applied plots. Similar results were found by Li et al. [10] that the application of chemical fertilizer (NPK) with cattle manure increased soil nutrient concentration and improved total organic carbon (54.7%), nitrogen (78.3%) and crop yield (39.6%) compared with single chemical fertilizer (NPK) application. Likewise, the organic sources with chemical fertilizers application enhanced the nutrient concentration in soil which had given positive effect on the nutrient uptake during the planting years. The organic sources with chemical fertilizer treatments showed the maximum nutrient plant uptake compared to chemical fertilizers alone application in rice plants during the three years planting period [42].

Table 6

Interactive effect of organic sources and mineral fertilizers on nutrient concentration in rice soil

Treatments	-------------- N (%) -----------			------------- P (ppm) -----------			------------ K (ppm) -----------		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
CF0+0	0.0201e	0.0196c	0.0216d	8.07e	9.31e	9.57f	108f	120e	143e
CFh+0	0.0234d	0.0224b	0.0242c	10.58c	10.68d	10.94de	178e	186d	211d
CFf+0	0.0243c	0.0249a	0.0261b	12.02b	13.26c	13.52c	188d	206bc	229c
CF0+FYM	0.0234d	0.0223b	0.0243c	8.81e	10.24d	12.08d	172e	184d	207d
CFh+FYM	0.0244c	0.0251a	0.0268b	10.39c	11.33d	13.90c	186d	197c	221c
CFF+FYM	0.0261b	0.0252a	0.0300a	14.74a	18.61a	18.87a	208b	220b	263a
CF0+PM	0.0237d	0.0224b	0.0245c	9.55d	11.52d	10.30e	174e	187d	213cd
CFh+PM	0.0264b	0.0228b	0.0270b	12.40b	13.64c	11.59d	194c	199c	243b
CFF+PM	0.0272a	0.0253a	0.0276b	15.38a	15.41b	15.67b	228a	240a	258a

* CF=chemical fertilizer, FYM=farmyard manure, PM= poultry manure. Means within the same column followed by the same letters are not significantly different at P>0.05

3.8 Interactive Effect of Organic Sources and Mineral Fertilizers on Nutrient Uptake in Rice Grain

The use of organic sources and chemical fertilizers with or without chemical fertilizer increased nutrient uptake during the planting years. The organic sources applied treatments with chemical fertilizers showed the higher nutrient uptake in grain compared to chemical fertilizers alone applied treatments. The significantly ($P<0.05$) the maximum grain N uptake 1.76 % and 1.71 % was found in PM with full rate of chemical fertilizer during the year 1 and year 2 whereas, in year 3 the maximum N 1.80 % was found in FYM with full chemical fertilizer application respectively (Table 7). Significantly ($P<0.05$) the maximum P uptake (0.23 %) was found in PM followed by FYM (0.22 %) at full rate of chemical fertilizer during the year 1 whereas, in year 2 and year 3 the highest grain P uptake (0.24 % and 0.23 %) was observed in FYM applied with full chemical fertilizer treatments respectively. The significantly ($P<0.05$) maximum K uptake in grain was recorded in 0.28 % and 0.30 % in PM with full chemical fertilizer application in year 1 and year 2 however, during the year 3 maximum K uptake (0.29 %) was reported in FYM with full chemical fertilizer applied treatments respectively (Table 7).

The application of poultry manure with chemical fertilizer accumulated the highest nutrients in soil as well plant uptake comparatively to FYM manure application. The maximum nutrients availability particularly N and P was might be due to the increase in decomposition of organic waste and lowering the soil pH [17]. Furthermore, the outcome of this study revealed a significant impact of organic sources with chemical fertilizers on growth and yield of rice crop. Additionally, application of both organic sources integrated with chemical fertilizer improve soil health, and physio-chemical properties of soil which lead to the increase of plant nutrient concentration and plant uptake and ultimately the higher grain and straw yield of rice crop during the consecutive three years rice planting period [40]. Similar trend of using organic sources in improving the soil properties, soil moisture retention, total N, organic C, available P, that all upsurge the soil fertility and growth and yield of rice crop [41].

Table 7

Interactive effect of organic sources and mineral fertilizers on nutrient uptake in rice grain

Treatments	----------- N (%) ---------			--------- P (%) ---------			--------- K (%) ---------		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 1	Year 2
CF0+0	0.88e	0.86d	0.83d	0.15c	0.14c	0.14d	0.23d	0.21d	0.22d
CFh+0	1.09c	1.14d	1.13c	0.15c	0.16c	0.16c	0.22c	0.25c	0.24c
CFf+0	1.55b	1.60b	1.59b	0.20a	0.21a	0.20b	0.24b	0.26c	0.25c
CF0+FYM	1.05c	1.10d	1.09c	0.17b	0.18b	0.19b	0.24b	0.26c	0.25c
CFh+FYM	1.26c	1.27c	1.20c	0.17b	0.19b	0.17c	0.25b	0.27b	0.26b

CFF+FYM	1.60b	1.67ab	1.80a	0.22a	0.24a	0.23a	0.27a	0.29a	0.28a
CF0+PM	1.07c	1.12d	1.11c	0.17b	0.18b	0.20b	0.24b	0.26c	0.25c
CFh+PM	1.62b	1.64b	1.61b	0.21a	0.22a	0.19b	0.25b	0.28b	0.27b
CFF+PM	1.76a	1.71a	1.68b	0.23a	0.23a	0.22a	0.28a	0.30a	0.29a

* CF=chemical fertilizer, FYM=farmyard manure, PM= poultry manure. This means within the same column followed by the same letters are not significantly different at P>0.05

The combined use of organic sources and mineral fertilizers had a synergistic effect, enhancing microbial abundance, plant growth, yield, and nutrient uptake in rice grains. Soil microorganisms play a crucial role in soil functions, including organic matter decomposition, nutrient cycling, and ecosystem stabilization, through various mechanisms. The application of organic compounds alongside mineral fertilizers promotes nutrient availability by stimulating beneficial microorganisms in the soil. The primary mechanism of these microbes is to produce organic acids and plant growth hormones, which improve nutrient availability and foster plant growth. Previous studies have also shown that combining a recommended dose of chemical fertilizer with poultry manure at different rates (0, 2.5, and 5 t ha^{-1}) significantly impacts rice growth and yield [18, 19].

4. Conclusion

The submission of various organic technologies (FYM and PM) in associated with mineral fertilizers enhanced microbial activity, abundance of beneficial bacteria in the rhizospheric soil during three years of rice cultivation. However, a decreasing trend in bacterial population was recorded in the chemical fertilizer application alone treatments. The use of organic nutrient sources improved rice growth promoting traits such as plant height, tiller numbers, panicles numbers, 1000 grain weight, straw and grain yield of rice along with mineral fertilizers. Hence, organic manure application along with chemical fertilizer showed the maximum microbial activities which directly increased certain bacterial species that played a major role in the breakdown of complex organic substances and affect the rice growth and yield by enhancing soil nutrient concentration and uptake which may lead to increased growth and yield of rice during the three years planting seasons.

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6. Institutional Review Board Statement

The Institutional Internal Review Committee has recommended this for publication.

Informed Consent Declaration: The authors assert that they have no conflicts of interest.

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