Original Research Article

EFFECT OF ENRICHED PHOSPHOCOMPOST ON SOIL BIOLOGICAL PROPERTIES OF PEARL MILLET IN VERTISOLS

Abstract

A field experiment was laid out with ten treatments replicated thrice in Randomized Block Design. Treatments comprised of T_1: control, T_2: 100% RDF, T_3: 100% RDF + 2.5 t bajra straw phosphocompost ha^{-1}, T_4: 100% RDF + 2.5 t cotton stalk phosphocompost ha^{-1}, T_5: 100% RDF + 2.5 t FYM ha^{-1}, T_6: 100% RDF + 5 t FYM ha^{-1}, T_7: 75% RDF + 2.5 t bajra straw phosphocompost ha^{-1}, T_8: 75% RDF + 2.5 t cotton stalk phosphocompost ha^{-1}, T_9: 75% RDF + 2.5 t FYM ha^{-1} and T_{10}: 75% RDF + 2.5 t FYM ha^{-1}. Soil biological properties were estimated at sowing, at flowering and harvesting of pearl millet. The experimental findings indicated that the soil microbial biomass were found to be increased at flowering than at sowing and further, gradually declined at harvest but higher than sowing stage. The significantly maximum soil microbial biomass C (212.42 µg C g^{-1} soil), N (70.72 µg N g^{-1} soil) and P (40.25 µg P g^{-1}) soil contents were recorded with 100% RDF + 2.5 t cotton stalks phosphocompost ha^{-1} (T_4) followed by 100% RDF + 2.5 t bajra straw phosphocompost ha^{-1} (T_3) at flowering. Among the FYM treatments, the higher SMBC, N and P were noted with 100% RDF + 5 t FYM ha^{-1} over 100% RDF alone. Further, it was noticed that C and N mineralization rate were increased at flowering stage and then declined at harvest as compare to sowing stage. However, at harvest, the highest C (9.12 µg C g^{-1} soil d^{-1}) and N (0.86 µg N g^{-1} soil d^{-1}) mineralization were recorded with 100% RDF + 2.5 t cotton stalks phosphocompost ha^{-1} (T_4) followed by 100% RDF + 2.5 t bajra straw phosphocompost ha^{-1} (T_3). Significantly maximum dehydrogenase activity (61.17 µg TPF g^{-1} soil 24 hr^{-1}), alkaline phosphatase activity (90.43µg*P*- Nitrophenol g^{-1} soil 24 hr^{-1}), fungal (23 × 10^{4}cfu g^{-1} soil), bacterial (43 × 10^{7}cfu g^{-1} soil) and actinomycetes (41 × 10^{6}cfu g^{-1} soil) population were noted in the treatment receiving 100% RDF + 2.5 t cotton stalks phosphocompost ha^{-1} (T_4).

Keywords: Phosphocompost, SMBC, SMBN, SMBP, Soil enzymatic activities, C and N mineralization.

1. Introduction

Phosphorus plays a crucial role in promoting early root growth, which helps seedlings establish themselves quickly. It supports a strong and vigorous start for plants, enhances stem strength, reduces the risk of lodging (falling over), and encourages crops to mature earlier. However, phosphorus in soil can become less available to plants due to immobilization, either through absorption or chemical precipitation, making it less soluble [1]. Therefore, demand of phosphorus can be met through application of organic manure in the form of phosphocompost and microbial inoculants to the plant. Soil microorganism plays a key role in soil P dynamics and subsequent availability of phosphate to plant.

Composts produced from rice straw enriched with rock phosphate and inoculated with *Aspergillus niger, Trichoderma viride* and/or farmyard manure (FYM) showed maximum amount of soluble phosphorus [2]. Biswas and Narayanasamy [3] developed a rock phosphate-enriched compost (RP-compost) by combining four low-grade Indian rock phosphates with rice straw, both with and without the use of *Aspergillus awamori*. The resulting RP-compost had higher levels of total phosphorus, citrate-soluble phosphorus, organic phosphorus, and both acid and alkaline phosphatase activity, while showing lower water-soluble phosphorus and microbial biomass carbon compared to regular compost. This suggests that RP-enriched compost could be an effective and sustainable method for utilizing low-grade rock phosphates and rice straw.

Cropping practices and the use of fertilizers or manure have a direct impact on soil microbial growth and activity. In tropical regions, plant material breaks down and microbial biomass turnover happens more quickly compared to temperate climates [4]. Organic supplements like cow dung, Leucaena leaves, farm residues, and Sesbania have been shown to increase soil organic carbon, microbial biomass carbon, and enzyme activities like urease and acid phosphatase [5]. Adding organic matter can improve soil health, boost organic carbon levels, and enhance crop yields. However, there is limited research on how different types of organic matter affect soil biological quality.

Material and Methods

A Field experiment was conducted at the farm of Bajra Research Scheme, College of Agriculture, Dhule. The experiment was laid out with ten treatments replicated thrice in Randomized Block Design. There were 10 treatments *viz.* T_1- Control, T_2- 100 % RDF, T_3- 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1}, T_4- 100% RDF+ 2.5 t Cotton stalks phosphocompost ha^{-1}, T_5- 100% RDF + 2.5 t FYM ha^{-1}, T_6- 100% RDF + 5 t FYM ha^{-1}, T_7- 75% RDF + 2.5 t Bajra straw phosphocompost ha^{-1}, T_8- 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1}, T_9- 75 % RDF + 2.5 t FYM ha^{-1}, T_{10}- 75% RDF + 5 t FYM ha^{-1}. The recommended dose of fertilizer for *kharif* pearl millet was 60:30:25 N: P_2O_5: K_2O kg ha^{-1}, respectively. The fertilizers, urea, single super phosphate and muriate of potash were used as a source of N, P and K, respectively. The half dose of N and full dose of P_2O_5 and K_2O were applied at the time of sowing, whereas remaining half dose of N was applied after the one month.

The phosphocompost prepared from bajra straw, cotton stalk and FYM were analyzed for their chemical composition and data placed in Table 1 and 2.

Table 1. Characterization of phosphocompost

Sr.No	Parameters	Bajra phosphocompost	Cotton phosphocompost
1	pH	7.3	7.4

2	EC (dSm^{-1})	0.63	0.43
3	Organic C (%)	24.88	26.60
4	Total N (%)	1.16	1.31
5	Total P (%)	1.68	1.85
6	Citrate soluble P (%)	0.81	0.88
7	Water Soluble P (%)	0.068	0.076
8	Total K (%)	0.85	0.75
9	C:N Ratio	21.44	20.31

Table 2. Characterization of FYM

Sr no	**Parameters**	**Contents**
1	pH	7.1
2	EC (dSm^{-1})	0.11
3	Organic C (%)	12
4	Total N (%)	0.61
5	Total P (%)	0.39
6	Total K(%)	0.79
7	C:N Ratio	19.67

In manure analysis, the organic carbon was determined by combustion method [6], the total N was analyzed by microkjeldahl method [7], the total P was analyzed by Vanadomolybdate blue colour colorimetric [8], the citrate and water soluble P was estimated by Colorimetric method [9] and the total K was determined by Flame photometry method [10]. In soil biological properties, the SMBC, SMBN and SMBP were determined by Chloroform fumigation extraction method [11], the CO_2 evolution by Alkali trap method [12], the NH_4 and NO_3 N by Distillation method [6], the soil microbial population were observed by Serial dilution plate method [13], the soil enzymatic activities DHA and alkaline phosphatase activities were determined by Spectrophotometric method [14] [15]. The data generated were statistically analysed in Randomized Block Design (RBD) as suggested by Panse and Sukhatme [16].

2. Result and Discussion

3.1 Effect of enriched phosphocompost application on soil microbial biomass C, N and P

3.1.1 Effect on soil microbial biomass carbon (SMBC)

At sowing stage, SMBC ranged from 120.16 to 152.63 µg C g^{-1} soil, and the higher values were recorded where the phosphocomposts and FYM were incorporated before sowing of crop (Table 3). Further, at flowering stage, the SMBC ranged between 132.27 to 212.42 µg C g^{-1} soil. Significantly highest microbial biomass carbon (212.42 µg C g^{-1} soil) was noted in treatment T_4 (100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1}) which was more superior than other treatments and followed by T_3 i.e. application of 100% RDF + 2.5 t bajra straw phosphocompost ha^{-1} (192.32 µg C g^{-1} soil). Application of these phosphocompost along with 75% RDF also recorded the higher values as compared to FYM. However, incorporation of 5 t FYM ha^{-1} significantly increased the SMBC over 2.5 t FYM ha^{-1}. The chemical fertilizer alone treatment (T_2) showed less SMBC (138.40 µg C g^{-1} soil) as compared to phosphocompost application. Similar trend was noticed at harvest of pearl millet and the microbial biomass C was ranged between 128.36 to 195.51 µg C g^{-1} soil. However, the magnitude of increase in SMBC at harvest with phosphocompost treatments i.e. T_3, T_4, T_7 and T_8 are of 38.12, 49.93, 22.85 and 32.12 per cent, respectively over 100% RDF alone. Further, it was noticed that SMBC increased from sowing to flowering stage and it gradually declined at harvest but values are quite higher than at sowing stage. The increase in soil microbial biomass carbon might be due to the higher microbial population and organic carbon as found in this study. This might create a calibrated soil quality indicator that only predicts whether soil is accumulating or losing soil carbon. The application of phosphocompost and farmyard manure (FYM) led to a significant increase in soil microbial biomass carbon compared to the initial levels observed in the control plot. However, the increase was less pronounced in plots where only chemical fertilizers were used. Similar increased in SMBC with phosphocompost application was noticed by Manna *et al*. [17] and with FYM application was showed by Mandal *et al*. [18].

3.1.2 Effect on soil microbial biomass nitrogen (SMBN)

At sowing of crop the SMBN varied from 13.94 to 22.36 µg N g^{-1} soil (Table 3). Further, at flowering stage the content was found significantly increased and it ranged between 22.48 to 70.72 µg N g^{-1} soil. The lowest content was recorded under control and the highest under 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} followed by 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (65.17 µg N g^{-1} soil). Application of these phosphocomposts along with 75% RDF also recorded the higher values as compared to FYM. However, incorporation of 5 t FYM ha^{-1} significantly increased the SMBC over 2.5 t FYM ha^{-1}. The chemical fertilizer alone treatment (T_2) showed less SMBN (28.32 µg N g^{-1} soil) as compared to INM. Similar trend was noticed at harvest of pearl millet and the microbial biomass N was ranged between 11.36 to 48.22 µg N g^{-1} soil. At this stage, application of bajra straw (T_3) and cotton stalks phosphocomposts (T_4) along with 100% RDF and their application with 75% RDF i.e. T_7 and T_8 treatments increases the SMBN by 119.36, 148.30, 96.91 and 114.01 per cent, respectively over 100% RDF alone (T_2) treatment. Further, it was noticed that SMBN increased from sowing to flowering stage and it gradually declined at harvest but values are quite higher than at sowing stage. The findings clearly showed that the levels of microbial biomass carbon (C) and nitrogen (N) varied depending on the sampling time. The highest levels were observed during the tillering stage, while the lowest occurred at the dough stage. Microbial biomass, though a small part of soil organic matter, is highly dynamic and can fluctuate by up to 40% depending on factors like weather, crop type, inputs, and season in both natural and agricultural ecosystems (Mandal *et al*. [18]). Significant increase in SMBN under different organic input was also reported by Tu *et al*. [19] and Thakare and Bhoyar [20].

3.1.3 Effect on soil microbial biomass phosphorous (SMBP)

Data inferred that at the time of sowing the SMBP was ranged from 9.48 to 20.17 µg P g^{-1} soil and the quite higher values of SMBP are noted in the plots where phosphocompost was applied before sowing (Table 3). Further, it was noticed that, at flowering stage, the SMBP found to be increased under all treatments as compared to at sowing stage. Significantly highest microbial biomass P was recorded in treatment T_4 (100% RDF+ 2.5 t Cotton stalks phosphocompost ha^{-1}) i.e. 40.25 µg P g^{-1} soil followed by the treatment T_3 i.e. 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (35.14 µg P g^{-1} soil). Among the remaining phosphocompost treatments, the cotton stalks phosphocompost with 75% RDF (T_8) recorded the higher (32.13 µg P g^{-1} soil) values as compared to T_6 (100% RDF + 5 t FYM ha^{-1}) and T_5 (100% RDF + 2.5 t FYM ha^{-1}) i.e. 25.70 and 23.62 µg P g^{-1} soil, respectively. The chemical fertilizer alone treatment (T_2) showed less (17.42 µg P g^{-1} soil) SMBP as compared to INM.

At the harvest of bajra, the SMBP was found to decline but was relatively higher over at sowing values. The lowest SMBP (10.17 µg C g^{-1} soil) was recorded under (T_1). Similarly, 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (T_4) and 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (T_3) showed higher values of SMBP i.e. 25.20 and 23.09 µg P g^{-1} soil, respectively as compared to other treatments. Although, appraisal of the results point out that the phosphocompost application treatments i.e. T_3, T_4, T_7 and T_8 increases SMBP by 74.01, 89.90, 55.61 and 71.21 per cent, respectively over 100% RDF alone (T_2).

The use of organic fertilizers significantly boosted soil microbial biomass of carbon (C), nitrogen (N), and phosphorus (P) across all sampling periods. In most cases, compost treatments resulted in a greater increase compared to manure, likely due to the microbial biomass present in the compost itself (Jannoura *et al*. [21]). Different types and amounts of organic compost had a notable impact on microbial biomass P and available P. Vermicompost treatments, in particular, showed a decline in both available P and microbial biomass P as the application rates decreased. Microbial biomass P produced declining trend with the reduction in application rate of FYM was previously noticed by Saha *et al*. [22].

Table 3. Effect of enriched phosphocompost application on SMBC, SMBN, SMBP, carbon mineralization and nitrogen mineralization

Treatments	SMBC (μg C g^{-1} soil)			SMBN (μg N g^{-1} soil)			SMBP (μg P g^{-1} soil)			C mineralization (μg C g^{-1} soil d^{-1})			N mineralization (μg N g^{-1} soil d^{-1})		
	At sowing	At flowering	At harvest	At sowing	At flowering	At harvest	At sowing	At flowering	At harvest	At sowing	At flowering	At harvest	At sowing	At flowering	At harvest
T_1	120.16	132.27	128.36	13.94	22.48	11.36	9.48	12.36	10.17	5.28	7.35	3.16	0.45	0.54	0.30
T_2	125.47	138.40	130.40	14.78	28.32	19.42	11.23	17.42	13.27	6.30	8.17	5.20	0.49	0.61	0.36
T_3	149.41	192.32	180.12	21.95	65.17	42.60	18.20	35.14	23.09	10.24	17.50	8.75	0.87	1.96	0.71
T_4	152.63	212.42	195.51	22.36	70.72	48.22	20.17	40.25	25.20	10.72	19.36	9.12	0.91	2.12	0.86
T_5	132.48	155.17	141.37	16.92	40.38	24.32	13.55	23.62	18.12	7.75	10.22	6.21	0.62	0.92	0.49
T_6	139.37	172.76	155.62	18.31	49.14	32.48	14.70	25.70	20.43	8.82	12.36	7.12	0.70	1.32	0.52
T_7	142.26	178.25	160.20	19.44	52.15	38.24	16.12	30.21	20.65	9.17	13.27	7.88	0.78	1.65	0.57
T_8	146.23	184.36	172.28	21.42	57.72	41.56	17.23	32.13	22.72	9.72	15.47	8.12	0.82	1.80	0.63
T_9	129.36	147.63	136.73	16.62	35.12	21.36	12.26	19.51	14.22	7.18	9.23	6.97	0.52	0.74	0.38
T_{10}	137.16	167.38	148.92	17.35	47.36	30.43	12.84	21.36	16.51	8.27	10.75	7.00	0.56	0.86	0.43
SE (m)±	0.31	0.28	0.41	0.38	0.41	0.50	0.33	0.37	0.35	0.18	0.27	0.19	0.008	0.008	0.008
CD at 5%	0.92	0.84	1.22	1.14	1.21	1.50	0.97	1.08	1.05	0.53	0.81	0.56	0.024	0.025	0.022

3.2 Effect of enriched phosphocompost application on carbon and nitrogen mineralization

The results on N mineralization were consistent with the differential effects of the plant residue treatments on C mineralization and microbial biomass. The results on N mineralization, C mineralization and microbial biomass were related to residue chemistry (Table 3). The study showed that phosphocompost and FYM in combination with chemical fertilizer had relatively high N concentration which accounted for the increased C and N mineralization and microbial biomass. The high C and N mineralization rate observed in the phosphocompost treatment in our study may also be partially due to enhanced activity of the soil fauna.

3.2.1 C Mineralization

At flowering stage of pearl millet, the C mineralization rate was slightly and significantly increased and it was varied from 7.35 to 19.36 µg C g^{-1} soil d^{-1}. The maximum C mineralization (19.36 µg C g^{-1} soil d^{-1}) was recorded with 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} followed by 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (17.50 µg C g^{-1} soil d^{-1}). However, the increase in C mineralization was also noticed for T_8 (75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1}) and T_7 (75% RDF + 2.5 t Bajra straw phosphocompost ha^{-1}) i.e. 15.47 and 13.27 µg C g^{-1} soil d^{-1}, respectively. The minimum rate of C mineralization (7.35 µg C g^{-1} soil d^{-1}) was recorded under control. Application of FYM along with 100% and 75% RDF significantly increased the C mineralization over 100% RDF alone, but values are lower as compared to phosphocompost treatments.

The cumulative levels of CO_2–C released increased rapidly from sowing until the flowering stage, after which they declined by the time of harvest. As time passed, the differences between treatments became more noticeable. The treatment with 100% NPK plus phosphocompost had the highest cumulative carbon mineralization throughout the period, while the control showed the lowest. These differences in carbon mineralization rates suggest varying amounts of easily degradable organic carbon were accumulated depending on the fertilizer treatment used (Rudrappa *et al*. [23]). Application of integrated nutrient supply increased C and N mineralization at grand growth stages of sorghum-wheat cropping system as compared to their individual application. Results showed that application of FYM + wheat straw + green manuring augmented C and N mineralization (Thakare, [24]).

3.2.2 N Mineralization

The rate of N mineralization at flowering stage was significantly increased and varied 0.54 to 2.12 µg N g^{-1} soil d^{-1}. 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (T_4) showed maximum N mineralization (2.12 µg N g^{-1} soil d^{-1}) and which was followed by T_3 i.e. 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (1.96 µg N g^{-1} soil d^{-1}). The 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} and 75% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} significantly increased the N mineralization rate over sole chemical fertilizer and INM with FYM. Although, FYM treatments significantly increases the N mineralization over chemical fertilizer.

The application of manure created conditions that enhanced the easily mineralizable inorganic nitrogen (N) pool, which was primarily in the form of ammonium. Total inorganic N mineralization was 45–48% higher in integrated nutrient management (INM) and organic nutrient management compared to chemical methods. This increase is due to the higher levels of organic matter, as N mineralization is a microbial process influenced by both the quantity and quality of soil organic matter, as previously noted by Dinesh *et al*. [25]. Similarly, Thakare [24] observed that integrated nutrient supply significantly boosted carbon (C) and nitrogen (N) mineralization during the grand growth stages of the sorghum-wheat cropping system compared to the early stages. Our results showed that enhanced soil microbial biomass N and C were associated with high N and C mineralization. The higher C and N mineralization rate in this study might be due to enhanced microbial populations and their activities.

3.3 Effect of enriched phosphocompost application on enzyamatic activities

3.3.1 Dehydrogenase activity (DHA)

The dehydrogenase activity was found to be reduced at harvest of pearl millet although, it was higher than at sowing stage (Table 4). At the end of cropping, the highest activity (61.17 µg TPF g^{-1} soil 24 h^{-1}) was noted with 100% RDF+ 2.5 t Cotton stalks phosphocompost ha^{-1} (T_4) followed by T_3 i.e. 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (58.32 µg TPF g^{-1} soil 24 h^{-1}). The 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} also recorded the higher (52.60 µg TPF g^{-1} soil 24 h^{-1}) dehydrogenase activity than chemical fertilizer. The dehydrogenase activity under 100% RDF along with 2.5 t Bajra straw phosphocompost ha^{-1} (T_3) and 2.5 t Cotton stalks phosphocompost ha^{-1} (T_4) and their application with 75% RDF i.e. T_7 and T_8 were increased by 90.77, 100.10, 57.77 and 72.06 per cent, respectively over 100% RDF alone (T_2).

Incorporating crushed cotton compost into soil can enhance enzymatic activities, as the compost may introduce both intra- and extracellular enzymes and stimulate microbial activity. This organic amendment, especially at higher doses, has a positive effect on enzyme activity, likely due to the increased microbial biomass it promotes, as observed by Tejada and Gonzalez [26]. Soil's biological and biochemical properties are often considered early and sensitive indicators of ecological stress or environmental changes. Since dehydrogenase activity occurs only in living cells, it reflects the overall oxidative activity of soil microorganisms and serves as a reliable indicator of microbial activity. In general, enzyme activity in soil is closely linked to organic matter content. The balanced application of nutrients and manures improves soil organic matter and microbial biomass carbon (MBC), which, in turn, enhances enzyme activity, as noted by Mandal *et al*. [18].

3.3.2 Alkaline phosphatase activity

Soil alkaline phosphatase activity indicated that at the start of experiment that is at sowing, the activity varied from 34.37 to 69.13 µg P- Nitrophenol g^{-1} soil 24 h^{-1}(Table 4). However, at flowering the activity was significantly increased and ranged from 50.17 to 145.53 µg P- Nitrophenol g^{-1} soil 24 h^{-1}. The maximum activity was recorded under 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (T_4) followed by 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (T_3), 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (T_8) and 75% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (T_7) i.e. 145.43, 132.71, 127.30 and 110.29 µg *P*- Nitrophenol g^{-1} soil 24 h^{-1}. FYM application @ of 2.5 and 5 t ha^{-1} along with 75% and 100% RDF significantly increases the activity of this enzyme as compared to RDF alone. Minimum activity was recorded for the sample collected from control plot.

At the end of cropping or at the harvest of pearl millet, the activity of this enzyme was declined but higher than its sowing status, however, the highest activity (90.43 µg *P*- Nitrophenol g^{-1} soil 24 h^{-1}) was noted with 100% RDF + 2.5 t cotton stalk phosphocompost ha^{-1} (T_4) followed by 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (T_3). Application of cotton salks phosphocompost and bajra straw phosphocompost along with 75% RDF significantly recorded higher alkaline phosphatase activity over FYM along with inorganic fertilizer treatments. However, FYM application (2.5 and 5 t ha^{-1}) along with RDF (75 and 100%) significantly enhanced the activity over 100% RDF alone. Further, it could be seen that the magnitude of increase of this enzyme activity is of 71.71 to 98.31 per cent for phosphocompost treated plots and 11.67 to 53.77 per cent for FYM over 100% RDF alone.

Alkaline phosphatase activity was higher in manure-amended plots compared to the control, with optimal and balanced fertilizer application further boosting phosphatase levels. A noticeable increase in alkaline phosphatase activity occurred during wheat cultivation, followed by a decline, highlighting the strong influence of the plant root zone on this enzyme, as noted by Masto *et al*. [27]. Compost-treated soils also showed significantly higher alkaline phosphatase activity than those treated with chemical fertilizers. In field experiments, phosphatase activity increased with compost application rates up to 90 Mg ha^{-1} and continued to rise linearly with rates up to 270 Mg ha^{-1}, as observed by Chang *et al*. [28]. The greater enzyme activity in farmyard manure (FYM) treated soils may be due to enhanced microbial activity and a greater diversity of phosphate-solubilizing bacteria from years of manure application. This activity was also closely linked to the microbial biomass carbon content, as noted by Mandal *et al*. [18].

Table 4. Effect of enriched phosphocompost application on DHA, alkaline phosphatase activity and soil microbial population

Treatments	DHA (μg TPF g^{-1} soil 24 hr^{-1})			Alkaline P activity (μg PNP g^{-1} soil 24 hr^{-1})			Fungal count (x 10^4 cfu g^{-1} soil)			Bacterial count (x 10^7 cfu g^{-1} soil)			Actinomycetes count (x 10^6 cfu g^{-1} soil)		
	At sowing	At flowering	At harvest	At sowing	At flowering	At harvest	At sowing	At flowering	At harvest	At sowing	At flowering	At harvest	At sowing	At flowering	At harvest
T_1	22.17	38.56	27.16	34.37	50.17	38.42	4	7	5	18	23	20	11	19	14
T_2	24.28	42.16	30.57	37.24	62.20	45.60	6	10	8	19	26	22	13	22	16
T_3	31.82	77.28	58.32	65.36	132.71	87.13	16	28	21	31	48	40	24	46	36
T_4	32.34	82.57	61.17	69.13	145.43	90.43	17	32	23	33	52	43	26	50	41
T_5	26.29	50.32	37.18	48.32	82.17	62.63	8	14	11	22	31	27	15	29	19
T_6	28.30	61.16	42.47	51.63	93.27	70.12	12	19	15	26	39	32	19	37	25
T_7	30.17	67.63	48.23	56.70	110.29	78.30	13	21	17	28	42	34	21	41	28
T_8	31.40	72.17	52.60	61.93	127.30	84.36	15	24	19	30	44	37	23	43	32
T_9	25.75	47.28	32.40	40.63	71.65	50.92	7	12	9	21	29	24	14	26	18
T_{10}	27.18	55.31	40.17	45.76	78.13	57.65	10	17	13	24	36	30	17	34	22
SE (m)±	0.43	0.58	0.47	0.42	0.48	0.34	0.70	0.48	0.59	0.54	0.48	0.50	0.38	0.55	0.52
CD at 5%	1.27	1.73	1.39	1.25	1.42	1.01	2.09	1.41	1.75	1.61	1.44	1.48	1.13	1.63	1.55

3.4 Effect of enriched phosphocompost application on soil microbial population

3.4.1 Soil fungal population

The fungal population was varied from 4.00 to 17.00 x 10^4 cfu g^{-1} soil, further, it was increased at flowering and than declined at harvest of pearl millet but values are found higher than at sowing stage (Table 4). At flowering stage of crop, significantly the maximum fungal population (32.00 x 10^4 cfu g^{-1} soil) was recorded with 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (T_4) followed by 100% RDF+ 2.5 t Bajra stalks phosphocompost ha^{-1} (T_3) i.e. 28 x 10^4 cfu g^{-1} soil. Significantly higher population over chemical fertilizer was also noted with 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} and 75% RDF + 2.5 t Bajra straw phosphocompost ha^{-1}. Although, the 5 t FYM ha^{-1} along with 100% RDF (T_6) and with 75% RDF (T_{10}) significantly enhanced the fungal population i.e. 19 and 17 x 10^4 cfu g^{-1} soil, respectively over 2.5 t FYM ha^{-1} with chemical fertilizer.

At harvest of pearl millet, the maximum fungal population (23 x 10^4 cfu g^{-1} soil) was noted in 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} followed by 100% RDF + 2.5 t bajra straw phosphocompost ha^{-1} (21 x 10^4 cfu g^{-1} soil). Higher population was also observed with 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} and 75% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} over 100% RDF alone. Further, FYM along with inorganic fertilizer treatments also significantly enhanced the fungal population as compared to inorganic fertilizer alone.

The regular addition of organic manures is essential for increasing soil organic matter. A 10-year study found that repeated applications of farmyard manure (FYM) resulted in a distinct microbial community compared to soils treated only with chemical fertilizers (Vineela *et al*. [29]). Thakare and Gupta [30] also explored how nutrient management affects microbial populations in vertisol soils. They observed a higher microbial population in plots receiving nitrogen through FYM, wheat straw, and green manure, compared to those treated with 100% NPK or left as a control. Similarly, Mahanta *et al.* [31] concluded that the continuous use of FYM had a positive impact on microbial populations.

3.4.2 Soil bacterial population

At sowing stage of crop, the bacterial populations were ranged between 18 to 33 x 10^7 cfu g^{-1} soil. Enhancement in bacterial population was observed at flowering stage and the ranged recorded was 23 to 52 x 10^7 cfu g^{-1} soil (Table 4). Significantly maximum population was noted with 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (52 x 10^7 cfu g^{-1} soil), also 100% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} showed second higher bacterial population (48 x 10^7 cfu g^{-1} soil). When comparing with 100% RDF alone, significant higher population were recorded with 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (44 x 10^7 cfu g^{-1} soil) and 75% RDF + 2.5 t Bajra straw (42 x 10^7 cfu g^{-1} soil). There was also increased in bacterial population in 100% RDF + 5 t FYM ha^{-1} (39 x 10^7 cfu g^{-1} soil) followed by 75% RDF + 5 t FYM ha^{-1} (36 x 10^7 cfu g^{-1} soil), 100% RDF + 2.5 t FYM ha^{-1} (31 x 10^7 cfu g^{-1} soil) and 75% RDF + 2.5 t FYM ha^{-1} (29 x 10^7 cfu g^{-1} soil) which were significantly higher over chemical fertilizer alone treatment.

At harvest of pearl millet, the integrated management practices enhanced the bacterial population over 100% RDF alone and control. The bacterial population recorded at the end of crop in phosphocomposts treatments viz., 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1}, 100% RDF +

2.5 t Bajra straw phosphocompost ha^{-1}, 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} and 75% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} was 43, 40, 37 and 34 x 10^7 cfu g^{-1} soil, respectively which were 95.45, 81.82, 68.18 and 54.54 per cent, respectively increase over 100% RDF alone treatment.

Soil populations of bacteria, actinomycetes, and fungi are influenced by both organic and inorganic nutrient management during different stages of crop growth. Tamilselvi *et al*. [32] found that the application of organic manures and crop residues, combined with phosphocompost, significantly affected fungal, bacterial, and actinomycetes populations. The highest populations were observed in treatments using farmyard manure (FYM) with phosphocompost, as well as pigeonpea stalk with phosphocompost, which outperformed chemical fertilizers. Nagar *et al*. [33] noted that the increased microbial population was likely due to the addition of organic manures and crop residues to the soil.

3.4.3 Soil actinomycetes population

Data inferred that at sowing stage the actinomycetes population ranged between 11 to 26 x 10^6 cfu g^{-1} soil (Table 4). Further, at flowering stage, it was increased and significantly maximum population was noted under 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (50 x 10^6 cfu g^{-1} soil) followed by 100% RDF + 2.5 t bajra stalks phosphocompost ha^{-1} (46 x 10^6 cfu g^{-1} soil). Followed by these treatments, the significantly higher actinomycetes population was observed under 75% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} (43 x 10^6 cfu g^{-1} soil) and 75% RDF + 2.5 t Bajra straw phosphocompost ha^{-1} (41 x 10^6 cfu g^{-1} soil) as compared to chemical fertilizer alone treatment (22.00 x 10^6 cfu g^{-1} soil). The 100% RDF + 5 t FYM ha^{-1} and 75% RDF + 5 t FYM ha^{-1} significantly enhanced the actinomycetes population over their reduced rate.

At the end i.e. at the harvest of pearl millet, the maximum actinomycetes population (41 x 10^6 cfu g^{-1} soil) was recorded with 100% RDF + 2.5 t Cotton stalks phosphocompost ha^{-1} followed by 100% RDF + 2.5 t bajra stalks phosphocompost ha^{-1} (36 x 10^6 cfu g^{-1} soil) which were found to be 156.25 and 125.00 per cent, respectively increased over 100% RDF alone. Rest of the treatments significantly increases the actinomycetes population over control.

Soil microbial biomass and the populations of bacteria, fungi, and actinomycetes were significantly higher in soils treated with compost compared to those treated with chemical fertilizers. Specifically, the populations of these microorganisms were notably greater in compost-amended soils than in those with no fertilizer or with chemical fertilizers. On average, microbial populations in compost-treated soils were 1.68 times higher than those in soils treated with chemical fertilizers, and these populations increased with higher compost application rates, as observed by Chang *et al*. [28]. Thakare and Bhoyar [20] also reported that bacterial and actinomycetes populations were highest in soils with both organic and inorganic inputs under soybean cultivation in vertisol. Additionally, Mahanta *et al*. [31] found that continuous application of farmyard manure (FYM) had a positive effect on microbial populations.

4. CONCLUSION:

Based on the experimental findings, the application of 100 % RDF+ 2.5 t Cotton stalks phosphocompost ha^{-1} and 100% RDF+ 2.5 t bajra straw phosphocompost ha^{-1} were enhanced soil biological activities in terms of SMBC, SMBN, SMBP, carbon and nitrogen mineralization. The enriched phosphocompost enhances soil enzymatic activities such as DHA, alkaline phosphatase and soil microbial population, including populations of bacteria, fungi, and actinomycetes compared to traditional chemical fertilizers.

Disclaimer: Authors hereby declare that NO generative AI technologies such as Large Language Models and text-to-image generators have been used during the writing or editing of manuscripts.

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