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Effect of Bioformulation-based Farming Systems on Soil Nutrient Content and Microbial Properties under Okra (*Abelmoschus esculentus* L.) Cultivation

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ABSTRACT

Background: Okra [*Abelmoschus esculentus* (L.) Moench] cultivation faces challenges associated with extensive chemical fertilizer use, prompting a shift towards sustainable practices. Organic inputs like poultry manure offer potential alternatives, yet their impact on soil health and crop productivity warrants investigation.

Methods: A two-year field experiment assessed the effects of bioformulation-based farming systems on soil properties and okra growth. Ten treatments incorporating organic amendments and bioformulations (pandchavya and jeevamrut) were evaluated in a randomized block design. Soil nutrient levels, microbial dynamics and enzyme activities were analyzed pre-and post-experiment.

Result: Combining 90% recommended nutrient dose with panchagavya and jeevamrut significantly enhanced soil nutrient content and microbial biomass. Increased bacterial, fungal and actinomycetes counts were observed alongside elevated enzyme activities.

Key words: Jeevamrut, Microbial, Okra, Organic bioformulations, Panchagavya.

INTRODUCTION

Okra [Abelmoschus esculentus (L.) Moench] is a globally cherished fruit vegetable known for its fibrous pods, cultivated predominantly in tropical regions during spring, summer and kharif seasons (FAOSTAT, 2021). However, the extensive use of chemical fertilizers in okra cultivation has raised concerns regarding soil degradation, productivity loss and potential food contamination with harmful residues. This situation has spurred a growing demand for sustainable agricultural practices, particularly those utilizing organic inputs.

In pursuit of sustainable growth and yield optimization, adequate nutrient provision, including nitrogen (N), potassium (K) and micronutrients, is crucial for okra cultivation. While traditional practices rely heavily on chemical fertilizers, the adverse environmental impacts necessitate alternative strategies. Poultry manure, renowned for its nutrient-rich composition, emerges as a viable organic substitute, enriching soil and promoting crop development (Boateng *et al*., 2006; Onwu *et al*., 2014). India, a major contributor to global okra production, is witnessing a shift towards organic inputs and sustainable agricultural practices. With over 546.46 thousand hectares dedicated to okra cultivation and an estimated production of 7158 thousand tonnes in 2022-2023 (Ministry of Agriculture and Farmer's Welfare, 2024), the need for eco-friendly farming methods is becoming increasingly urgent.

Bioformulation fertilizers, as part of smart fertilizer strategies, have shown promise in enhancing nutrient availability and crop production (Karthik and Maheswari, 2020). This study aims to explore the relationship between soil properties, nutrient content, microbial dynamics and okra growth within bioformulation-based farming systems.

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By investigating the influence of various organic amendments and bioformulations on soil health and plant productivity, we seek to shed light on their effectiveness in promoting sustainable agricultural practices.

MATERIALS AND METHODS

The experiment was carried out at the Department of Soil Science and Water Management, College of Forestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P) during the *Kharif* seasons of 2020 and 2021. The experiment was laid out in randomized block design with ten treatments and three replications during *Kharif* seasons 2020 and 2021. The sources of nutrients were vermicompost, poultry manure and organic liquid manures (panchagavya, jeevamrut). The experiment comprised of three replications with a plot size of 1.5 m × 1.5 m.

The recommended nutrient doses were applied using a 50:50 ratio of vermicompost and poultry manure based on nitrogen equivalence. These were mixed with soil before seed sowing. Panchagavya (5%) and jeevamrut (5%) organic liquid formulations (Table 1 and 2) were applied twice at 250 ml per plant, as soil drenches, at 15-day intervals starting two weeks after sowing until the third fruit harvest. The experiment comprised 10 treatments: T_1: 100% RDN, T_2-T_4: 90% RDN with panchagavya (5%), jeevamrut (5%) and panchagavya (5%) + jeevamrut (5%) respectively; T_{5}-T_7: 80% RDN with the same formulations; and T_8-T_{10}: 70% RDN with the same formulations.

The physico-chemical properties of soil were analyzed before as shown in Table 3 and after the experiment, focusing on pH (Jackson, 1973), organic carbon (Walkley and Black, 1934), available nitrogen (Subbiah and Asija, 1956), phosphorus (Olsen *et al*., 1954), potassium (Merwin and Peech, 1951), copper, iron, zinc and manganese (Lindsay and Norvell, 1978) using standard methods. Soil samples were collected, air-dried, sieved and stored. Microbial properties were assessed through viable microbial count (Subba Rao, 1999) and total microbial biomass (Vance *et al*., 1987). Enzyme activities *viz*., dehydrogenase, phosphatase, urease were measured using standard methods given by Casida *et al*. (1964); Tabatabai and Bremner (1969) and Hoffman (1965) respectivelty. Statistical analysis was performed using ANOVA on a randomized block design with LSD at $p \leq 0.05$ significance level.

RESULTS AND DISCUSSION

Physico-chemical and nutritional status of soil

The aggregated data from Table 4 indicates that none of the tested treatments significantly affected soil pH and EC. The pH values ranged from 6.35 to 6.56 and EC values ranged from 0.17 dS m^{-1} to 0.29 dS m^{-1}. However, the application of various organic manures significantly influenced soil organic carbon levels. The pooled analysis in Table 4 showed that the highest organic carbon content (24.32 g kg^{-1}) was observed under treatment T_4 [90% RDN + panchgavya @ 5% + jeevamrut @ 5%], while the lowest (20.58 g kg^{-1}) was recorded in treatment T_9 [70% RDN + jeevamrut @ 5%]. The observed increase in soil organic carbon is consistent with the findings of Bhadhulkar *et al.* (2000) and Selvi *et al*. (2004), who reported long-term application of FYM enhancing soil properties. Similarly, bioformulation fertilizers have been noted to improve nutrient availability and microbial biomass, thereby supporting sustainable agricultural practices (Kumar and Brar, 2021).

Available macronutrients

Table 5 shows a significant rise in soil nitrogen content after applying various organic amendments. Treatment T_4 [90% RDN + panchgavya @ 5% + jeevamrut @ 5%] displayed the highest nitrogen value (418.0 kg ha^{-1}), a 26% increase over the control [T_1 (100% RDN)], as shown in Fig 1. This increase is attributed to nutrient-rich organic manures like vermicompost and poultry manure, as noted by Ullah *et al.* (2008). Likewise, T_4 exhibited a notable increase in available phosphorus content, reaching 78.22 kg ha^{-1}, a 30% rise compared to the control, consistent with findings by Ray *et al*. (2005) and Sharma *et al*. (2008). Furthermore, T_4 showed a significant elevation in available potassium content, recording 423.7 kg ha^{-1}, a 22.03% increase over the control, supported by research conducted by Aziz *et al.* (2010). Roy and Kashem (2014) also support these findings, emphasizing the effectiveness of organic manures like cow dung and chicken manure in improving soil nutrient

Table 1: Composition of panchgavya.

Ingredients	Quantity
Cow Dung	5 kg
Cow urine	4 litre
Cow milk	2 litres
Cow ghee	1 kg
Cow curd	3 kg
Jaggery	2 kg
Sugarcane juice	2 litres
Coconut	1 fruit
Banana	1 dozen

*Dilution of 5 litres of panchagavya in 100 litres of water for soil application.

Table 2: Composition of jeevamrut.

Ingredients	Quantity
Cow dung	10 kg
Cow urine	10 litres
Jaggery	2 kg
Pulse flour	1 kg
Live soil	1 kg
Water	200 litres

*Dilution of 5 litres of Jeevamrut in 100 litres of water for soil application.

Table 3: Soil properties of the experimental site before the start of the experiment.

Properties	Values	
	2020	2021
pH (1:2)	6.48	6.97
EC (dS m^{-1})	0.17	0.16
Organic carbon (%)	2.03	2.05
Available N (kg ha^{-1})	299.12	300.01
Available P (kg ha^{-1})	54.83	55.15
Available K (kg ha^{-1})	298.3	297.98
DTPA extractable Cu (mg kg^{-1})	3.06	3.16
DTPA extractable Zn (mg kg^{-1})	2.15	2.18
DTPA extractable Fe (mg kg^{-1})	15.88	15.91
DTPA extractable Mn (mg kg^{-1})	10.29	10.39

Table 4: Effect of organic manures on soil physico-chemical properties.

Treatments	pH			EC (dS m^{-1})			Organic carbon (g/kg)		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1: 100% RDN*	6.43	6.46	6.44	0.22	0.28	0.25	21.90	21.50	21.70
T_2: 90% RDN + Pancahagavya @ 5%	6.33	6.37	6.35	0.18	0.15	0.17	23.40	22.60	23.00
T_3: 90% RDN + Jeevamrut @ 5%	6.43	6.47	6.45	0.31	0.28	0.29	22.17	21.60	21.88
T_4: 90% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	6.45	6.51	6.48	0.25	0.23	0.24	24.50	24.13	24.32
T_5: 80% RDN + Pancahagavya @ 5%	6.42	6.44	6.43	0.18	0.19	0.18	22.07	21.70	21.88
T_6: 80% RDN + Jeevamrut @ 5%	6.56	6.56	6.56	0.24	0.28	0.26	22.17	22.13	22.15
T_7: 80% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	6.48	6.49	6.48	0.26	0.21	0.24	23.57	22.83	23.20
T_8: 70% RDN + Pancahagavya @ 5%	6.56	6.54	6.55	0.23	0.22	0.22	21.93	21.93	21.93
T_9: 70% RDN + Jeevamrut @ 5%	6.4	6.41	6.4	0.21	0.23	0.22	20.77	20.40	20.58
T_{10}: 70% RDN + Pancahagavya @ 5% + Jeevamrut @ 5%	6.52	6.51	6.51	0.18	0.24	0.21	23.10	23.27	23.18
CD $_{(P\leq 0.05)}$	NS	NS		NS	NS		1.01	1.25	

RDN*- Recommended Doses of Nutrients; *Significant at P≤0.05; NS- Non Significant at P>0.05.

Table 5: Effect of organic manures on available macronutrients (kg ha^{-1}) content in soil.

Treatments	Available macronutrients (kg ha^{-1})								
	N			P			K		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1: 100% RDN*	330.2	330.1	330.2	59.22	61.04	60.13	345.1	349.2	347.2
T_2: 90% RDN + Pancahagavya @ 5%	332.5	332.2	332.3	69.96	70.01	69.98	360.0	363.0	361.5
T_3: 90% RDN + Jeevamrut @ 5%	351.2	351.0	351.1	75.15	75.52	75.34	369.4	370.4	369.9
T_4: 90% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	417.7	418.4	418.0	77.22	79.22	78.22	422.8	424.6	423.7
T_5: 80% RDN + Pancahagavya @ 5%	361.1	362.8	361.9	67.67	69.12	68.40	378.8	379.3	379.1
T_6: 80% RDN + Jeevamrut @ 5%	377.4	378.2	377.8	62.07	63.74	62.91	384.1	387.7	385.9
T_7: 80% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	398.0	398.0	398.0	72.85	73.03	72.94	417.8	419.1	418.4
T_8: 70% RDN + Pancahagavya @ 5%	298.2	307.7	303.0	59.56	58.64	59.14	348.5	355.9	352.2
T_9: 70% RDN + Jeevamrut @ 5%	298.6	299.3	298.9	55.83	59.08	57.45	321.6	323.3	322.4
T_{10}: 70% RDN + Pancahagavya @ 5% + Jeevamrut @ 5%	398.3	397.5	397.9	72.14	73.04	72.59	414.4	415.8	415.1
CD $_{(P\leq 0.05)}$	12.74	12.68		0.81	1.21		14.86	11.82	

RDN*- Recommended doses of nutrients; *Significant at P≤0.05; NS- Non significant at P>0.05.

Table 6: Effect of organic manures on DTPA extractable cations.

Treatments	DTPA extractable micronutrients (mg kg^{-1})											
	Cu			Fe			Zn			Mn		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1: 100% RDN*	3.14	3.16	3.15	15.61	17.12	16.37	2.23	2.26	2.25	10.48	10.49	10.48
T_2: 90% RDN + Pancahagavya @ 5%	3.73	3.74	3.73	16.78	17.22	17.00	2.77	2.78	2.77	11.92	11.89	11.91
T_3: 90% RDN + Jeevamrut @ 5%	3.92	3.94	3.93	17.80	18.14	17.97	2.46	2.50	2.48	10.99	11.01	11.00
T_4: 90% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	4.61	4.64	4.62	19.83	19.91	19.87	3.01	2.99	3.00	12.80	12.84	12.82
T_5: 80% RDN + Pancahagavya @ 5%	3.75	3.83	3.79	17.30	18.03	17.67	2.65	2.68	2.67	11.42	11.46	11.44
T_6: 80% RDN + Jeevamrut @ 5%	3.82	3.83	3.82	16.70	16.81	16.76	2.52	2.54	2.53	11.28	11.30	11.29
T_7: 80% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	4.30	4.32	4.31	19.21	20.00	19.60	2.93	2.95	2.94	12.61	12.65	12.63
T_8: 70% RDN + Pancahagavya @ 5%	3.82	3.83	3.82	16.81	17.03	16.92	2.64	2.68	2.66	11.45	11.45	11.45
T_9: 70% RDN + Jeevamrut @ 5%	3.38	3.36	3.37	16.18	18.54	17.36	2.34	2.37	2.36	10.67	10.77	10.72
T_{10}: 70% RDN + Pancahagavya @ 5% + Jeevamrut @ 5%	4.08	4.09	4.08	18.23	19.39	18.81	2.85	2.87	2.86	12.13	12.18	12.16
CD $_{(P\leq 0.05)}$	0.08	0.11		0.26	0.76		0.05	0.08		0.16	0.17	

RDN*- Recommended doses of nutrients; *Significant at P≤0.05; NS- Non significant at P>0.05.

Table 7: Effect of organic manures on viable microbial count of soil.

Treatments	Bacteria (× 10^8 cfu g^{-1})			Fungi (× 10^3 cfu g^{-1})			Actinomycetes (× 10^2 cfu g^{-1})		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1: 100% RDN*	140.7	143.7	142.2	3.22	3.16	3.19	2.50	2.71	2.61
T_2: 90% RDN + Pancahagavya @ 5%	175.0	178.3	176.7	3.42	3.55	3.49	3.15	3.17	3.16
T_3: 90% RDN + Jeevamrut @ 5%	165.0	167.3	166.2	3.45	3.67	3.56	2.79	2.79	2.79
T_4: 90% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	202.7	204.0	203.3	4.16	4.42	4.29	3.66	3.71	3.69
T_5: 80% RDN + Pancahagavya @ 5%	173.7	173.3	173.5	3.67	3.78	3.72	2.86	2.87	2.86
T_6: 80% RDN + Jeevamrut @ 5%	159.0	157.7	158.3	3.56	3.56	3.56	2.77	2.74	2.76
T_7: 80% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	188.0	194.7	191.3	4.08	4.15	4.12	3.18	3.20	3.19
T_8: 70% RDN + Pancahagavya @ 5%	166.3	168.7	167.5	3.88	3.73	3.80	2.85	2.92	2.89
T_9: 70% RDN + Jeevamrut @ 5%	154.3	157.3	155.8	3.04	3.42	3.23	2.64	2.67	2.65
T_{10}: 70% RDN + Pancahagavya @ 5% + Jeevamrut @ 5%	186.0	184.0	185.0	4.07	4.02	4.05	3.30	3.30	3.30
CD $_{(P\leq 0.05)}$	2.84	1.52		0.03	0.01		0.09	0.11	

RDN*- Recommended doses of nutrients; cfu- Colony forming unit; *Significant at P≤0.05; NS- Non significant at P>0.05.

Table 8: Effect of organic manures on microbial biomass-C (µg g^{-1} soil).

Treatments	Microbial biomass-C (µg g^{-1} soil)		
	2020	2021	Pooled
T_1: 100% RDN*	44.91	47.35	46.13
T_2: 90% RDN + Pancahagavya @ 5%	55.38	57.20	56.29
T_3: 90% RDN + Jeevamrut @ 5%	49.41	51.08	50.24
T_4: 90% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	63.52	66.52	65.02
T_5: 80% RDN + Pancahagavya @ 5%	56.08	57.70	56.89
T_6: 80% RDN + Jeevamrut @ 5%	51.93	53.82	52.87
T_7: 80% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	61.12	62.04	61.58
T_8: 70% RDN + Pancahagavya @ 5%	54.22	55.55	54.88
T_9: 70% RDN + Jeevamrut @ 5%	47.58	48.57	48.08
T_{10}: 70% RDN + Pancahagavya @ 5% + Jeevamrut @ 5%	61.04	62.08	61.56
CD $_{(P\leq 0.05)}$	1.54	2.98	

RDN*- Recommended doses of nutrients; *Significant at P≤0.05; NS- Non significant at P>0.05.

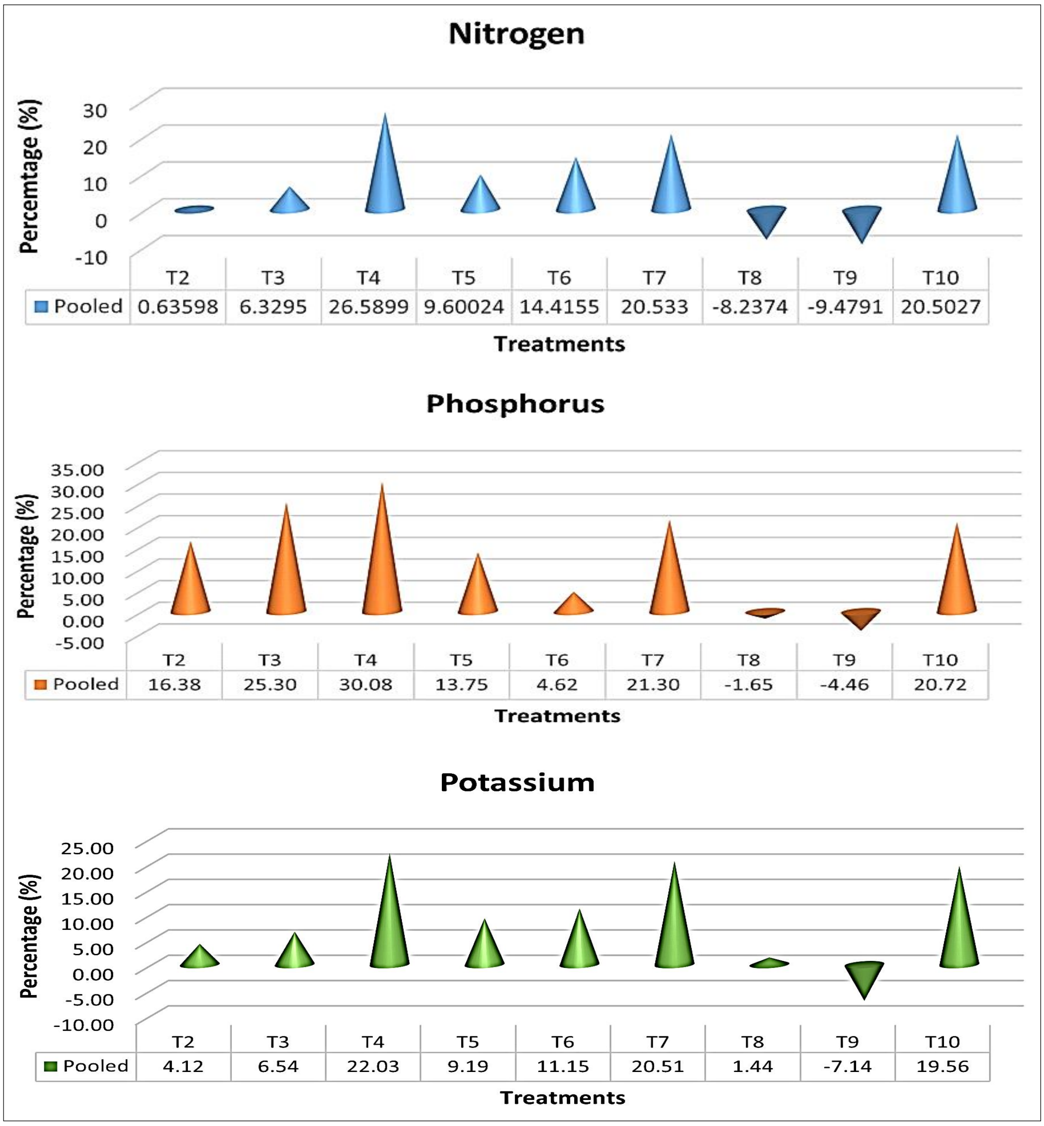

Fig 1: Per cent increase/decrease in available NPK over 100% recommended dose of nutrients.

status. Across both experimental years, T_4 consistently enriched soil nutrients, highlighting the effectiveness of bioformulation-based farming systems in enhancing soil fertility and promoting optimal crop growth.

DPTA extractable cations

Table 6's pooled analysis emphasizes the significant influence of various organic manures on soil DPTA extractable cations. Furthermore, the examination of available micronutrient cations in Table 6 reveals notable differences due to organic manure application. Particularly, treatment T_4 [90% RDN + panchgavya @ 5% + jeevamrut @ 5%] displays the highest levels of available micronutrient cations, including Cu, Fe, Zn and Mn, at 4.62 mg kg^{-1}, 19.87 mg kg^{-1}, 3.00 mg kg^{-1} and 12.82 mg kg^{-1}, respectively. These values indicate a substantial increase compared to the control treatment [T_1 (100% RDN)]. This enhancement aligns with previous studies by Beckman (1973) and Udah *et al*. (2005), which reported positive effects of organic manure usage on soil micronutrient levels. Additionally, Reddy and Reddy (1999) support these findings, highlighting the role of organic manures in boosting available soil micronutrients. Overall, the results suggest that organic manure application, especially treatment T_4, significantly boosts micronutrient cation availability compared to the control, consistent with previous research emphasizing the positive impact of organic manure on soil micronutrient levels.

Soil microbial properties

Microbial count

Table 7 illustrates the impact of organic amendments on soil microbial populations. Treatment T_4 [90% RDN + panchgavya @ 5% + jeevamrut @ 5%] recorded the highest bacterial count (203.34 $\times 10^8$ cfu g^{-1} soil), while T_1 [100% RDN] had the lowest (142.2 $\times 10^8$ cfu g^{-1} soil). Similarly, T_4 showed the highest fungal count (4.29 $\times 10^3$ cfu g^{-1} soil) and the highest actinomycetes count (3.69 $\times 10^2$ cfu g^{-1} soil), with T_1 having the lowest counts (3.19 $\times 10^3$ cfu g^{-1} soil for fungi and 2.61 $\times 10^2$ cfu g^{-1} soil for actinomycetes). These results align with previous research (Jain *et al*., 2014).

Microbial biomass

Table 8 shows that microbial biomass-C was highest in T_4 (65.02 µg g^{-1} soil) and lowest in T_1 (46.13 µg g^{-1} soil). Treatment T_4 showcased the highest microbial biomass-C, contrasting with T_1 displaying the lowest. This aligns with findings by Dou *et al*. (2023), highlighting increased microbial biomass in organic tomato farming systems with organic inputs and straw mulching. The observed enhancements emphasize the positive repercussions of organic farming practices on soil microbial activity.

Soil enzymes

Table 9 illustrates the significant impact of different treatments on soil dehydrogenase activity over both study years. T_4 [90% RDN + panchgavya @ 5% + jeevamrut @

Table 9: Effect of organic manures on soil enzymes.

Treatment	Dehydrogenase (mg TPF h^{-1} g^{-1} soil)			Phosphatase (µmole PNP h^{-1} g^{-1} soil)			Urease (mg NH^+ g^{-1} soil)		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1: 100% RDN*	2.94	2.88	2.91	19.35	19.07	19.21	0.16	0.16	0.16
T_2: 90% RDN + Pancahagavya @ 5%	4.18	4.20	4.19	23.02	23.37	23.20	0.23	0.24	0.23
T_3: 90% RDN + Jeevamrut @ 5%	4.09	4.24	4.17	25.07	26.03	25.55	0.24	0.25	0.24
T_4: 90% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	4.87	4.73	4.80	31.35	30.60	30.98	0.30	0.29	0.29
T_5: 80% RDN + Pancahagavya @ 5%	3.89	3.92	3.91	26.17	25.79	25.98	0.20	0.21	0.20
T_6: 80% RDN + Jeevamrut @ 5%	4.06	4.10	4.08	20.60	20.57	20.58	0.18	0.19	0.18
T_7: 80% RDN + Pancahagavya @ 5%+ Jeevamrut @ 5%	4.24	4.35	4.30	27.36	28.03	27.70	0.26	0.25	0.25
T_8: 70% RDN + Pancahagavya @ 5%	3.31	3.40	3.36	20.49	20.23	20.36	0.17	0.18	0.17
T_9: 70% RDN + Jeevamrut @ 5%	4.26	4.33	4.29	27.37	28.04	27.71	0.25	0.23	0.24
T_{10}: 70% RDN + Pancahagavya @ 5% + Jeevamrut @ 5%	4.01	4.03	4.02	22.58	22.62	22.60	0.21	0.22	0.21
Mean	3.98	4.02	4.00	24.34	24.44	24.39	0.22	0.22	0.22
C.D. $_{(0.05)}$	0.11	0.19		1.00	0.81		0.01	0.02	

RDN*- Recommended doses of nutrients; TPF- Triphenylformazan; PNP- p-nitrophenol; *Significant at Pd"0.05; NS- Non significant at P>0.05.

5%] showed the highest dehydrogenase activity (4.80 mg TPF h^{-1} g^{-1} soil), followed by T_7 (4.30 mg TPF h^{-1} g^{-1} soil), while T_1 exhibited the lowest activity (2.91 mg TPF h^{-1} g^{-1} soil). Additionally, phosphatase activity was notably influenced by various organic amendments across both years, with T_4 displaying the highest activity (30.98 µmole PNP h^{-1} g^{-1} soil) and T_1 the lowest (19.21 µmole PNP h^{-1} g^{-1} soil), consistent with Krishnakumar *et al.* (2005), who observed increased phosphatase activity with FYM application. Furthermore, urease enzyme activity varied among treatments, with T_4 showing the highest activity (0.29 mg NH^{+} g^{-1} soil) and T^1 the lowest (0.16 mg NH^{+} g^{-1} soil). These results emphasize the significant impact of different treatments on soil enzyme activity, with T4 displaying the highest dehydrogenase and phosphatase activities and T^1 showing the lowest. Similarly, T_4 exhibited the highest urease activity, while T_1 had the lowest, aligning with Chandrakala (2008), indicating increased enzyme activity with organic input application, such as FYM. Kashyap and Khokhar (2017) further support these results, linking improved urease activity to FYM application and enhanced crop productivity. Overall, these findings underscore the positive influence of organic farming practices on soil microbial properties and enzyme activity, promoting soil health and fertility. They highlight the significance of sustainable agricultural practices aimed at fostering soil biological activity to sustain long-term agricultural productivity.

CONCLUSION

The thorough evaluation of soil characteristics and nutrients after applying organic amendments offers vital insights into sustainable farming. While minimal impact is seen on pH and EC, organic manure notably boosts soil organic carbon, indicating enhanced fertility and carbon storage potential. Treatment T_4 consistently proves most effective in enriching soil properties and microbial activity. This highlights the importance of bio-based farming, like Panchgavya and Jeevamrut, for soil health and crop yield. The importance of bioformulation-based farming systems, such as Panchagavya and Jeevamrut, in promoting soil health and crop yield has been increasingly recognized. Smart fertilizer strategies incorporating bioformulation fertilizers offer a viable path towards sustainable agriculture. Future research should focus on the lasting effects of organic manure, with longitudinal studies across multiple crop cycles. Exploring interactions with practices like crop rotation and cover cropping could optimize productivity and reduce environmental harm. A multidisciplinary approach merging soil science, agronomy, microbiology and agroecology is essential for tackling agricultural challenges sustainably, ensuring resilient and productive farming systems while safeguarding the environment.

Author's contribution

Conceptualization and designing of research work (F. Lalkhumliana, Rajesh Kaushal); Execution of field/lab experiments and data collection (F. Lalkhumliana); Analysis of data and interpretation (F. Lalkhumliana, S. Ananthakrishnan); Preparation of manuscript (F. Lalkhumliana, S. Ananthakrishnan).

Conflict of interest

All authors declare that they have no conflict of interest.

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