Agric Res J ***62*** *(3): 331-344, June 2025*
DOI: 10.5958/2395-146X.2025.00040.4

IMPACT OF ORGANIC BIOFORMULATIONS ON SOIL MICROBIAL PROPERTIES, YIELD, AND QUALITY OF OKRA (*Abelmoschus esculentus* L.)

F Lalkhumliana[a], Rajesh Kaushal[a], Ananthakrishnan S[a], Vishnu Shankar[b], Gitanjili Rathore[c] and Noel Lalhruaitluangi[d]

[a]*Department of Soil Science and Water Management, Dr YS Parmar University of Horticulture and Forestry, Solan-173 230, Himachal Pradesh, India*
[b]*Department of Basic Sciences, Dr YS Parmar University of Horticulture and Forestry, Solan-173 230, Himachal Pradesh, India*
[c]*Department of Soil Science, Punjab Agricultural University, Ludhiana-141 004, Punjab, India*
[d]*Department of Horticulture, Mizoram University, Aizawl-796 004, Mizoram, India*

ABSTRACT

A field experiment was conducted over two consecutive *kharif* seasons (2020-2021) to evaluate the effect of organic bioformulations on soil microbial properties, yield, and quality of okra (*Abelmoschus esculentus* L.). The trial included ten treatments involving combinations of recommended nutrient doses (RDN) with organic inputs such as vermicompost, poultry manure, *panchagavya*, and *jeevamrut*. Results revealed that the treatment combining 90% RDN with *panchagavya* and *jeevamrut* significantly enhanced microbial biomass carbon (65.02 μg g^{-1} soil), bacterial (203.3 × 10^{8} cfu g^{-1}), fungal (4.29 × 10^{3} cfu g^{-1}), and actinomycetes populations (3.69 × 10^{2} cfu g^{-1}), as well as soil enzymatic activities. This treatment also recorded the highest plant height (156.4 cm), dry biomass (63.36 g plant^{-1}), fruit yield (12.58 t ha^{-1}), and quality traits such as fruit length (12.04 cm), diameter (3.88 cm), and TSS (5.46 °Brix). The findings emphasize the effectiveness of integrated organic nutrient management in enhancing soil biological activity and sustainable okra production.

Keywords: Bioformulations, *Jeevamrut*, Okra, Organic farming, *Panchagavya*, Soil microbes

Okra (*Abelmoschus esculentus* (L.) Moench) continues to hold significant value as a vegetable crop, particularly in tropical and subtropical regions. Its widespread appeal lies in both its culinary flexibility and nutritional richness, offering ample vitamins, minerals, and dietary fiber. India remains the top producer, with the crop grown over 546.46 thousand hectares and producing approximately 7,158 thousand tonnes, based on the latest figures from the Ministry of Agriculture and Farmers' Welfare (2024).

While the use of chemical fertilizers has undeniably boosted agricultural productivity in recent decades, it has also brought serious challenges. Prolonged and excessive reliance on synthetic inputs has deteriorated soil health, reduced microbial biodiversity, and, in some cases, led to chemical residues in both the environment and the food chain (Pahalvi *et al.*, 2021; Shen *et al.*, 2021; Yadav *et al.*, 2021). These growing concerns have encouraged many to look towards organic farming methods as a sustainable alternatives.

Corresponding author: flalkhumliana@gmail.com
Date of receipt: 04.04.2024, Date of acceptance: 16.05.2025

Organic inputs such as vermicompost, poultry litter, and traditional formulations like *panchagavya* and *jeevamrut* have demonstrated effectiveness in enhancing soil vitality. These amendments not only supply essential nutrients but also enhance microbial activity in the soil, which is crucial for nutrient cycling and overall plant health (Subbaiah, 2019; Brar *et al.*, 2020). The biologically active components and microbial populations in indigenous preparations like *panchagavya* and *jeevamrut* enrich the root zone, enhance enzyme activity, and improve crop growth (Gopal and Gurusiddappa, 2022.).

Even though there is growing research interest in organic inputs, there remains a lack of detailed studies exploring how these bioformulations affect soil microbial dynamics, especially in open-field vegetable production systems like okra. Much of the current work focuses on yield or nutrient uptake, with limited insights into the underlying biological interactions. This study aims to address that gap by evaluating the combined effects of organic manures and liquid bioformulations on soil microbiology, okra productivity, and fruit quality. The intention is to contribute practical knowledge that can inform ecologically sound and effective nutrient management practices in organic farming.

MATERIALS AND METHODS

The experiment was carried out during the *kharif* seasons of 2020 and 2021 at the Organic Research Farm of Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India (30.86°N latitude and 77.10°E longitude, at an altitude of 1275 m above mean sea level). The field had been under organic management for more than three years before the study, with no application of synthetic fertilizers or agrochemicals. In the cropping season preceding the experiment, Bell pepper was grown on the same plot. The soil of the site is classified as an Inceptisol (Eutrochept subgroup), moderately acidic (pH 6.48), with low electrical conductivity (0.17 dS m^{-1}), and had an initial organic carbon content of 2.03%, providing favorable conditions for microbial evaluation under organic farming systems.

The experiment to evaluate the effect of organic manures on soil properties and yield of okra was laid out in Randomized Block Design with ten treatments and three replications during *kharif* 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 (Table 1) were supplied using a 50:50 mixture of vermicompost and poultry manure, calculated based on their nitrogen content. The quantities of both inputs were standardized to achieve nitrogen equivalence and fully incorporated into the soil prior to sowing. Additionally, two traditional organic formulations, *panchagavya* (5%) and *jeevamrut* (5%), were applied as soil drenches @ 250 ml per plant, beginning two weeks after sowing and repeated at 15-days intervals until the third fruit harvest.

The experiment comprised 10 treatments:

- T_1: 100% recommended dose of nutrients (RDN)
- T_2: 90% RDN + *Panchgavya* @ 5%
- T_3: 90% RDN + *jeevamrut* @ 5%
- T_4: 90% RDN + *panchagavya* (5%) + *jeevamrut* (5%)
- T_5: 80% RDN + *Panchgavya* @ 5%
- T_6: 80% RDN + *jeevamrut* @ 5%
- T_7: 80% RDN + *panchagavya* (5%) + *jeevamrut* (5%)
- T_8: 70% RDN + *Panchgavya* @ 5%
- T_9: 70% RDN + *jeevamrut* @ 5%
- T_{10}: 70% RDN + *panchagavya* (5%) + *jeevamrut* (5%)

Nutrient doses in all treatments were applied through a vermicompost and poultry manure blend (50: 50), with amounts adjusted to meet nitrogen requirements (Table 2). The *panchagavya* and *jeevamrut* liquid formulations (referenced in Tables 3 and 4) were consistently applied as per the described schedule. Uniform cultural practices were maintained across all treatments throughout the experiment.

Table 1. Recommended doses of nutrients (RDN) for okra

Nutrients	Quantity/ ha	Quantity/ plot (2.25 m^2)
FYM	100 q ha^{-1}	2.25 kg
N	75 kg ha^{-1}	16.8 g
P_2O_5	50.4 kg ha^{-1}	11.34 g
K_2O	54 kg ha^{-1}	12.15 g

Table 2 Nutrient content in farm yard manure, vermicompost and poultry manure

Manures	Nutrient content (%)		
	N	P_2O_5	K_2O
Farm Yard Manure	0.50	0.20	0.50
Vermicompost	1.75	1.50	1.20
Poultry Manure	2.75	2.63	1.60

Table 3. 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

Flowchart of preparation of *panchagavya*

1. • Mix thoroughly the fresh cow dung + cow*ghee*
2. •Incubate for 3 days
3. •Add cow urine
4. •Stir properly (morning and evening, daily for one week)
5. •Add sugarcane juice & jaggery
6. •Add cow milk + cow curd + coconut + 12 bananas
7. •Stir properly (morning and evening, daily for 3 weeks)
8. •*Panchagavyais* ready for soil drenching/ spray

Table 4. 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

Flow chart of preparation of jeevamrut

1. •Add fresh cow dung + cow urine in water
2. •Mix jaggery + pulse flour and live soil in water
3. •Mix the above both and stir properly (morning and evening) for 4 days
4. •On fifth day filter the solution and filtrate is ready for soil drenching/ spray

Soil microbial enumeration

The viable populations of soil bacteria, fungi, and actinomycetes were estimated using the serial dilution and standard spread plate method described by Subbarao (1999). One gram of fresh composite soil sample was suspended in 9 mL of sterile distilled water and serially diluted up to 10^{-6}. From appropriate dilutions, 0.1 mL of each suspension was plated in triplicate onto selective culture media: Nutrient Agar (NA) for bacteria, Potato Dextrose Agar (PDA) for fungi, and Kenknight and Munaier's medium for actinomycetes. The plates were incubated at 28 ± 2 °C for 48 hours for bacterial colonies, and 5-7 days for fungal and actinomycete colonies, depending on growth characteristics. Colony counts were recorded, and microbial populations were expressed as colony-forming units per gram of dry soil (cfu g^{-1} soil).

Microbial biomass carbon (MBC)

Soil microbial biomass carbon was estimated using the chloroform fumigation-extraction method as detailed by Vance *et al.* (1987). Fresh soil samples were split into fumigated and non-fumigated portions. The fumigated samples were exposed to ethanol-free chloroform for 24 hours, while non-fumigated samples served as controls. Both were extracted using 0.5 M K_2SO_4, and the extractable organic carbon was analyzed using a Total Organic Carbon analyzer. Microbial biomass carbon was calculated as the difference between fumigated and unfumigated samples, multiplied by a factor of 0.38 (k_eC), and expressed in µg C g^{-1} soil.

Soil enzyme activities

Dehydrogenase activity was determined using the method proposed by Casida *et al.* (1964). Soil samples were incubated with 2,3,5-triphenyltetrazolium chloride (TTC), and the amount of triphenyl formazan (TPF) formed was measured at 485 nm using a spectrophotometer. Phosphatase activity was estimated as per Tabatabai and Bremner (1969) by incubating soil with p-nitrophenyl phosphate and quantifying the released p-nitrophenol at 420 nm. Urease activity was measured following Hoffman (1965), where soil was treated with a urea solution and the ammonium released was determined colorimetrically.

Growth parameters and sampling

Each experimental plot measured 1.5 × 1.5 m, with plant spacing maintained at 45 cm between rows and 20 cm within rows. From each plot, five plants were selected for growth parameter analysis using a systematic random sampling approach. A random starting point was generated, and plants were selected at fixed intervals across rows to ensure unbiased representation.

Growth parameters recorded included plant height (from base to apex using a meter scale), plant biomass (dry weight after 24 h shade drying followed by oven-drying at 60 °C to constant weight), and days to first flowering (from transplanting to first flower opening). Root mass density was assessed at harvest from 0-15 cm soil depth using a metallic core (8.1 cm internal diameter, 11.22 cm height). Roots were washed using fine mesh and micro-jet water, and dry weight was divided by core volume:

Root mass density (g cm^{-3}) = Dry weight of roots / Volume of core

Manual irrigation was applied daily or as needed based on soil moisture. Weeding was conducted biweekly.

Yield and quality parameters

Five randomly selected plants per plot were used to assess yield attributes. Marketable fruit counts and total fruit weight per plant were recorded, with yields converted to t ha^{-1}. Fruit size parameters (length and diameter) were measured during the second and fifth harvests using a meter scale and Vernier calipers, respectively. Ten fruits per plot were randomly sampled using a random number generator.

Total Soluble Solids (TSS) were measured on fruit juice using an Erma hand refractometer (0-32% range) and expressed as °Brix, with temperature correction to 20 °C as per AOAC (1980).

Experimental notes

Ten harvests were completed in the 2020 season. In 2021, pest (blister beetle) and disease pressures (Cercospora leaf spot, leaf blight, and root knot nematode infestation by *Meloidogyne incognita*) were observed, which may have contributed to reduced yield in the second year.

Nutrient content and uptake

After collecting and drying plant samples of fruits, leaves, stem, and roots, the total macro (N, P, K) and micro (Cu, Fe, Zn, and Mn) nutrients were analyzed. Nitrogen was estimated using the micro-Kjeldahl method described in AOAC (1970). For P, K, and micronutrients, the plant samples were wet digested in a triacid mixture, and phosphorus was determined by the vanadomolybdo phosphoric yellow color method (Piper, 1973), while K was measured by flame photometer (Jackson, 1973). The estimation of micronutrient content (Cu, Zn, Fe, and Mn) was done using atomic absorption spectrophotometry (AAS). Nutrient uptake was also calculated based on the nutrient content estimation.

Statistical analysis

The recorded data were analyzed statistically using Microsoft Excel and OPSTAT (Sheoran *et al*., 1998). A one-way analysis of variance (ANOVA) was performed on the combined 2-year dataset based on a randomized block design (RBD). The least significant difference (LSD) was determined among the factors at $p \leq 0.05$.

RESULTS AND DISCUSSION

Plant growth parameters

The application of diverse organic manures significantly influenced okra plant growth parameters, including plant height, dry biomass, and root mass density (Table 5). Treatment T_4, which combined 90% recommended dose of nitrogen (RDN) with *panchagavya* and *jeevamrut*, resulted in the tallest plants (156 cm), marking a significant 20% increase (Fig. 1) over the control (T_1). Similarly, T_4 recorded the highest dry biomass at 63.36 g plant^{-1}, which was significantly more than the biomass observed in T_1 (28.7 g plant^{-1}). In the case of root mass density, T_4 achieved a value of 19.67 × 10^4 mg m^{-3}, which was significantly greater than the 14.16 × 10^4 mg m^{-3} recorded in T_1.

The synergistic application of bulky organic manures and liquid bioformulations significantly enhances soil structure, microbial activity, and nutrient availability. Organic manures, such as farmyard manure (FYM), improve soil organic carbon content, water-holding capacity, and microbial biomass, leading to better soil fertility and plant growth (Talwar *et al.,* 2017). Liquid biofertilizers, rich in beneficial microorganisms, further boost soil enzymatic activities and nutrient cycling, ensuring efficient nutrient uptake by crops (Manohar *et al*., 2018). The combined use of these organic inputs not only enhances nutrient use efficiency but also promotes sustained plant growth and resilience against environmental stresses.

Yield and its attributes

The pooled results revealed that the application of organic formulations significantly influenced the number of fruits per plant and total fruit yield (Table 6). Treatment T_4 (90% RDN + *panchagavya* + *jeevamrut*) recorded the highest number of fruits per plant (13.78), whereas T_1 exhibited the lowest

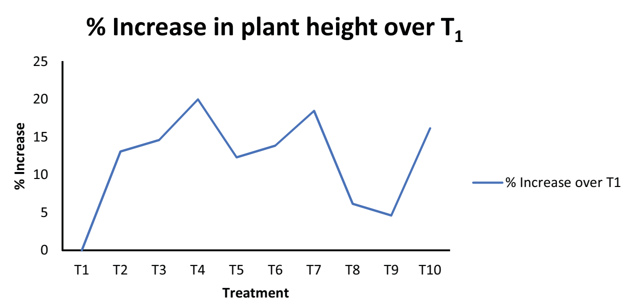

Fig. 1. Percent increase in plant height in different treatments

Table 5. Effect of bulky organic manures and liquid organic formulations on plant height, dry biomass and root mass density

Treatments	Plant height (cm)			Dry biomass (g plant^{-1})			Root mass density (mg m^{-3} x 10^{4})		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1^*	130	129	130	28.1	29.4	28.7	14.2	14.2	14.2
T_2	147	147	147	36.7	38.4	37.5	16.3	17.4	16.8
T_3	150	148	149	36.7	38.4	37.6	16.9	17.0	17.0
T_4	156	156	156	62.0	64.8	63.4	19.6	19.7	19.7
T_5	146	147	146	35.4	37.0	36.2	16.6	16.8	16.7
T_6	146	149	148	35.9	37.5	36.7	17.5	18.3	17.9
T_7	154	155	154	59.4	62.1	60.7	18.2	18.3	18.3
T_8	138	138	138	42.4	44.3	43.4	15.8	16.5	16.2
T_9	136	137	136	36.4	38.1	37.2	17.1	18.1	17.6
T_{10}	151	152	151	57.9	60.5	59.2	18.1	19.1	18.6
CD $_{(p \leq 0.05)}$	*5.81*	*7.86*	*5.30*	*2.21*	*1.98*	*1.79*	*0.82*	*1.00*	*1.02*

*T_1: 100% recommended dose of nutrients (RDN), T_2: 90% RDN + *Panchgavya* @ 5%, T_3: 90% RDN + *jeevamrut* @ 5%, T_4: 90% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_5: 80% RDN + *Panchgavya* @ 5%, T_6: 80% RDN + *jeevamrut* @ 5%, T_7: 80% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_8: 70% RDN + *Panchgavya* @ 5%, T_9: 70% RDN + *jeevamrut* @ 5%, T_{10}: 70% RDN + *panchagavya* (5%) + *jeevamrut* (5%)

(10.75). Treatments T_7 (13.22) and T_{10} (13.19) also showed comparable fruit numbers to T_4. Similarly, pooled fruit yield was highest under T_4, which produced 12.57 t ha^{-1}, compared to the lowest yield of 8.02 t ha^{-1} observed in T_1. The percent increase in fruit yield over treatment T_1 is illustrated in Figure 2. These results clearly indicate that the integration of liquid bioformulations with organic manures significantly enhanced okra productivity.

The improved yield performance under T_4 can be attributed to the synergistic action of organic manures and liquid formulations, which may have enhanced nutrient availability, stimulated microbial activity in the rhizosphere, and improved plant vigor. *Panchagavya* and *jeevamrut* are known to contain phytohormones, enzymes, and beneficial microbes that contribute to

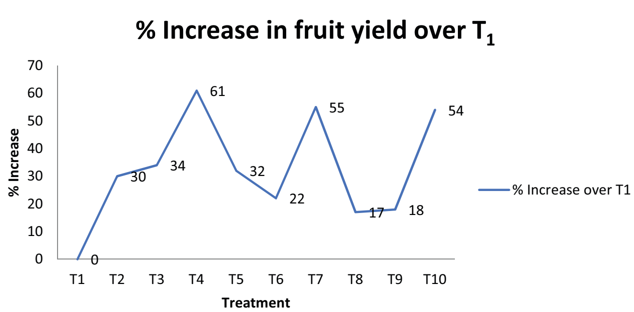

Fig. 2. Percent increase in fruit yield in different treatments

better flowering, fruit set, and nutrient uptake. These findings are consistent with recent studies. For instance, the combined application of *jeevamrutha* and *panchagavya* significantly enhanced soil nutrient status, microbial populations, and crop yields in cowpea and groundnut (Sujith and Devakumar, 2017; Patel *et al.*, 2018). Similarly, *panchagavya* enhanced plant growth and nutrient uptake in crops like ginger and blackgram (Chitra and Vinothini, 2020; Choudhary *et al.*, 2017). From a broader perspective, the results highlight the effectiveness of combining bulky and liquid organic amendments to achieve sustainable yield gains in vegetable crops. In the context of organic farming, such integrated approaches not only improve productivity but also enhance soil health and ecological resilience. These findings support the inclusion of liquid bioformulations as a vital component of organic nutrient management strategies in long-term sustainable agriculture.

Quality of fruits

The pooled data showed that fruit quality attributes such as fruit length, diameter, and average fruit weight were significantly influenced by the application of various organic manures and liquid formulations (Table 7). Among all treatments, T_4 (90% RDN + *panchagavya* + *jeevamrut*) consistently recorded the highest values: fruit length of 12.04 cm, diameter of 3.88 cm, and fruit weight of 12.86

Table 6. Effect of bulky organic manures and liquid organic formulations on number of fruits per plant and fruit yield (t ha^{-1})

Treatments	Number of fruits per plant			Fruit yield (t ha^{-1})		
	2020	2021	Pooled	2020	2021	Pooled
T_1*	10.94	10.55	10.75	8.83	7.71	7.80
T_2	12.36	11.39	11.88	12.41	7.90	10.16
T_3	12.26	11.58	11.92	12.43	8.40	10.42
T_4	13.76	13.79	13.78	13.22	11.94	12.58
T_5	11.59	11.54	11.57	11.66	8.86	10.26
T_6	11.37	11.44	11.41	11.23	7.85	9.54
T_7	13.21	13.23	13.22	14.96	9.25	12.10
T_8	11.32	11.04	11.18	10.94	7.30	9.12
T_9	12.05	11.54	11.79	10.88	7.57	9.22
T_{10}	13.17	13.20	13.19	14.39	9.65	12.02
CD $_{(p\leq0.05)}$	*0.47*	*0.63*	*0.35*	*0.53*	*0.32*	*0.44*

*T_1: 100% recommended dose of nutrients (RDN), T_2: 90% RDN + *Panchgavya* @ 5%, T_3: 90% RDN + *jeevamrut* @ 5%, T_4: 90% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_5: 80% RDN + *Panchgavya* @ 5%, T_6: 80% RDN + *jeevamrut* @ 5%, T_7: 80% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_8: 70% RDN + *Panchgavya* @ 5%, T_9: 70% RDN + *jeevamrut* @ 5%, T_{10}: 70% RDN + *panchagavya* (5%) + *jeevamrut* (5%)

g. In contrast, T_1 recorded the lowest values for these parameters. Additionally, the pooled data for total soluble solids (TSS), which was significantly influenced by the treatments, is illustrated in Figure 3, showing a 24% increase in TSS under T_4 compared to T_1.

The improvement in quality traits under T_4 can be attributed to the synergistic role of organic inputs in enhancing nutrient availability, root uptake efficiency, and metabolic functions related to fruit development. Liquid organic formulations like *panchagavya* and *jeevamrut* are known to contain growth-promoting hormones, beneficial microbes, enzymes, and micronutrients that directly or indirectly influence cell division, fruit expansion, and sugar accumulation.

These results align with findings from recent

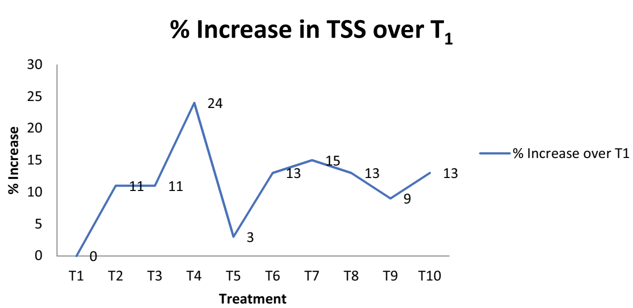

Fig. 3. Effect of bulky organic manures and liquid organic formulations on percent increase of TSS (° Brix) as compared to T_1

studies. Organic manures and biofertilizers have been shown to significantly improve fruit morphology, nutritional quality, and yield in vegetable crops. For example, integrated applications of farmyard manure and biofertilizers enhanced fruit quality and nutrient content in lemon trees, including improved leaf mineral content and fruit size (Ennab, 2016). Organic nutrition sources like poultry manure and compost were also found to enhance summer squash fruit weight and sugar content (Hafez *et al*., 2016).

These enhancements highlight the multifunctional role of organic amendments, not just in yield improvement but also in elevating crop quality to meet both nutritional and market standards. The rise in TSS under organic treatments may be associated with improved photosynthetic activity and carbohydrate translocation, reinforcing the ecological benefits of microbial-driven nutrient cycles over synthetic inputs. As consumer demand increasingly favours produce that is both health-conscious and environmentally sustainable, adopting integrated organic practices like those in T_4 offers a viable pathway for high-quality, residue-free vegetable production. These results support a shift towards diversified organic nutrient strategies that enrich soil biology while producing nutritionally superior crops.

Nutrient content

The pooled results also indicated that nutrient

Table 7. Effect of bulky organic manures and liquid organic formulations on fruit length, fruit diameter and fruit weight)

Treatment	Fruit length (cm)			Fruit diameter (cm)			Fruit weight (g)		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1*	8.99	8.77	8.88	2.19	2.23	2.21	9.31	10.48	9.89
T_2	9.69	10.11	9.90	2.93	2.99	2.96	11.29	10.97	11.13
T_3	10.03	10.29	10.16	3.03	2.97	3.00	11.39	10.86	11.12
T_4	11.92	12.17	12.04	3.80	3.97	3.88	12.88	12.83	12.86
T_5	10.03	10.36	10.20	3.00	2.95	2.98	11.26	11.08	11.17
T_6	9.66	10.72	10.19	2.90	3.01	2.96	11.10	11.11	11.10
T_7	11.00	11.12	11.06	3.62	3.70	3.66	12.69	12.07	12.38
T_8	9.63	10.41	10.02	2.64	2.85	2.75	10.80	10.79	10.52
T_9	9.70	10.14	9.92	2.73	2.78	2.76	10.19	10.73	10.46
T_{10}	10.33	10.22	10.27	3.08	2.83	2.96	10.92	10.89	10.90
CD $_{(p \leq 0.05)}$	*0.52*	*0.50*	*0.42*	*0.15*	*0.14*	*0.13*	*0.63*	*0.51*	*0.36*

*T_1: 100% recommended dose of nutrients (RDN), T_2: 90% RDN + *Panchgavya* @ 5%, T_3: 90% RDN + *jeevamrut* @ 5%, T_4: 90% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_5: 80% RDN + *Panchgavya* @ 5%, T_6: 80% RDN + *jeevamrut* @ 5%, T_7: 80% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_8: 70% RDN + *Panchgavya* @ 5%, T_9: 70% RDN + *jeevamrut* @ 5%, T_{10}: 70% RDN + *panchagavya* (5%) + *jeevamrut* (5%)

accumulation in okra plants was significantly influenced by the application of various organic inputs. Treatment T_4 (90% RDN + *panchagavya* + *jeevamrut*) showed significant improvements in both macro- and micronutrient content compared to T_1 (100% RDN through FYM). Specifically, T_4 recorded a 14% increase in nitrogen, 6% in phosphorus, and 21% in potassium over T_1. Similarly, for micronutrients, T_4 showed a 16% increase in iron (Fe), 24% in zinc (Zn), 31% in copper (Cu), and 32% in manganese (Mn). These findings are presented in Fig. 4.

The observed increases in macro- and micronutrient content under T_4 highlight the synergistic benefits of integrating liquid organic bioformulations with bulky organic manures. *panchagavya* and *jeevamrut*, though not nutrient-dense in themselves, are rich in beneficial microbes, plant growth regulators, and enzyme stimulants that enhance nutrient solubilization and root absorption efficiency. When combined with 90% RDN through FYM, these formulations appear to optimize nutrient uptake pathways without compromising overall nutrient supply.

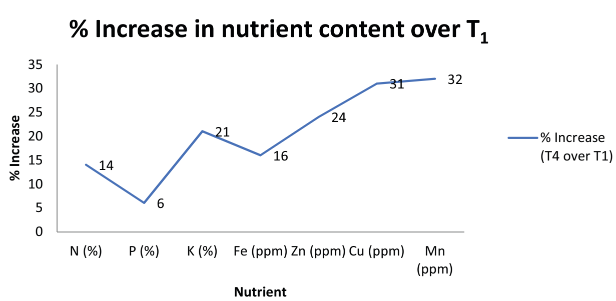

Fig. 4. Effect of bulky organic manures and liquid organic formulations on percent increase in nutrient content

While T_1 received a full dose of nutrients via FYM, the addition of liquid bioformulations in T_4 may have stimulated microbial activity in the rhizosphere, accelerating mineralization and improving nutrient mobility. This is supported by studies showing that integrated use of organic manures and liquid formulations significantly enhances microbial biomass and enzymatic activity, improving nutrient cycling and soil fertility (Neufeld *et al.,* 2017). Farmyard manure and bio-slurry also improved nutrient content and soil pH while increasing fresh yields in crops like Chinese cabbage (Mwanga, 2016). Additionally, liquid and pelleted digestates from manure have been found to enhance nutrient availability and stimulate microbial processes, contributing to improved plant nutrient uptake and biomass (Valentinuzzi *et al.,* 2020).

This clearly demonstrates the principle that organic nutrient management is not only about quantity, but also about biological efficiency. Bioformulations support a biologically active soil environment that facilitates more efficient nutrient acquisition and internal redistribution within the plant.

Nutrient uptake

The pooled data revealed that total nitrogen, phosphorus, and potassium uptake by okra plants varied significantly across treatments (Table 8). Among all treatments, T_4 (90% RDN + *panchagavya* + *jeevamrut*) recorded the highest uptake values, with 53.41 kg ha^{-1} of nitrogen, 6.28 kg ha^{-1} of phosphorus, and 45.84 kg ha^{-1} of potassium. In contrast, T_1 (100% RDN through FYM) recorded comparatively lower uptake levels for all three nutrients.

The higher uptake of N, P, and K under T_4 reflects the enhanced nutrient availability and absorption efficiency resulting from the integration of bulky organic manures with liquid bioformulations. While FYM supplies a gradual release of macro-nutrients, the addition of *panchagavya* and *jeevamrut* promotes microbial proliferation and enzymatic activity in the rhizosphere, leading to better nutrient solubilization and mobilization.

These findings align with recent research demonstrating the positive effects of *vermicompost*, *jeevamrut*, and cow dung slurry on crop yield, microbial activity, and nutrient uptake. Vermicompost application has been shown to significantly enhance tomato yield, nutrient uptake, and fruit quality parameters such as lycopene and ascorbic acid content (Bhattacharjee *et al.,* 2015; Durukan *et al.,* 2019). Similarly, integrating cow dung with poultry waste for vermicomposting increased tomato yield and nutrient availability (Jayakumar and Kanimozhi, 2017). Biofortified vermicompost enriched with beneficial microbes like Trichoderma and Pseudomonas further improved antioxidant levels and plant growth (Bisen and Singh, 2019).

In the context of organic farming, these results highlight the potential of combining solid and liquid organic inputs to not only improve soil health but also maximize nutrient uptake by crops. This approach contributes to sustainable crop production by reducing dependency on external chemical inputs alongwith ensuring sufficient nutrient supply for optimal plant growth and yield.

Soil microbial properties

a) Microbial count

The pooled data revealed that soil microbial populations, including bacteria, fungi, and actinomycetes, were significantly influenced by the application of various organic amendments (Table 9). Among all treatments, T_4 (90% RDN + *panchagavya* @ 5% + *jeevamrut* @ 5%) recorded the highest microbial counts across all groups, with the bacterial population reaching 203.34 × 10^8 cfu g^{-1} soil, fungal population at 4.29 × 10^3 cfu g^{-1} soil, and actinomycetes count at 3.69 × 10^2 cfu g^{-1} soil. In contrast, the lowest values for all microbial groups were observed under T_1 (100% RDN through FYM).

Table 8. Effect of bulky organic manures and liquid organic formulations on nutrient uptake by plant

Treatment	Nutrient uptake (kg ha^{-1})								
	N			P			K		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1*	27.07	27.00	27.04	3.31	3.40	3.36	21.00	21.19	21.10
T_2	30.48	30.97	30.73	3.88	4.08	3.98	24.16	28.01	26.09
T_3	35.46	34.26	34.86	4.08	3.98	4.03	25.94	26.26	26.10
T_4	54.27	52.54	53.41	6.28	6.27	6.28	44.37	47.31	45.84
T_5	29.50	27.80	28.65	3.62	3.48	3.55	24.25	22.11	23.18
T_6	30.65	30.30	30.48	3.60	3.59	3.60	24.98	27.01	26.00
T_7	47.49	48.56	48.03	5.70	6.04	5.87	41.87	41.87	41.87
T_8	28.57	28.33	28.45	4.20	4.12	4.16	26.89	27.37	27.13
T_9	23.64	23.97	23.81	3.51	3.40	3.46	21.34	22.45	21.90
T_{10}	34.81	34.43	34.62	5.23	5.04	5.14	32.41	31.27	31.84
CD $_{(p\leq 0.05)}$	*2.12*	*1.64*	*1.36*	*0.19*	*0.20*	*0.17*	*0.93*	*1.11*	*1.51*

*T_1: 100% recommended dose of nutrients (RDN), T_2: 90% RDN + *Panchgavya* @ 5%, T_3: 90% RDN + *jeevamrut* @ 5%, T_4: 90% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_5: 80% RDN + *Panchgavya* @ 5%, T_6: 80% RDN + *jeevamrut* @ 5%, T_7: 80% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_8: 70% RDN + *Panchgavya* @ 5%, T_9: 70% RDN + *jeevamrut* @ 5%, T_{10}: 70% RDN + *panchagavya* (5%) + *jeevamrut* (5%)

The significant enhancement in microbial populations under T_4 highlights the critical role of integrating liquid bioformulations with bulky organic manures in stimulating soil biological activity. *Panchagavya* and *jeevamrut* are known to be rich in beneficial microbial consortia, organic acids, enzymes, and growth-promoting substances that create a favorable environment for microbial proliferation in the rhizosphere.

The observed increase in bacterial, fungal, and actinomycetes populations under T_4 suggests improved soil aeration, organic carbon availability, and moisture retention-all factors that support microbial growth. These results are consistent with recent findings showing that applications of fermented cow dung slurry and *jeevamrut* significantly enhance microbial populations in soil, including bacteria, fungi, and actinomycetes (Bondre *et al.,* 2019; Kaur*,* 2020). These inputs enhance microbial diversity and colony-forming units, thereby improving soil biological activity and nutrient cycling. Application of these organic inputs boosts microbial biomass and enzyme activity, further improving nutrient cycling and soil health.

From the perspective of organic farming, fostering a diverse and active microbial community is essential for nutrient cycling, disease suppression, and long-term soil fertility. The findings of this study reinforce the ecological value of organic formulations not only in enhancing crop growth but also in building resilient and biologically active soil systems.

b) Microbial biomass

The pooled data revealed that soil microbial populations, including bacteria, fungi, and actinomycetes, were significantly influenced by the application of various organic amendments (Table 9). Among all treatments, T_4 (90% RDN + *panchagavya* @ 5% + *jeevamrut* @ 5%) recorded the highest microbial counts across all groups, with the bacterial population reaching 203.34 × 10^8 cfu g^{-1} soil, fungal population at 4.29 × 10^3 cfu g^{-1} soil, and actinomycetes count at 3.69 × 10^2 cfu g^{-1} soil. In contrast, the lowest values for all microbial groups were observed under T_1 (100% RDN through FYM).

The significant enhancement in microbial populations under T_4 highlights the critical role of integrating liquid bioformulations with bulky organic manures in stimulating soil biological activity. *Panchagavya* and *jeevamrut* are known to be rich in beneficial microbial consortia, organic acids, enzymes, and growth-promoting substances that create a favourable environment for microbial proliferation in the rhizosphere.

The observed increase in bacterial, fungal, and actinomycetes populations under T_4 suggests improved soil aeration, organic carbon availability, and moisture retention, all factors that support

Table 9. Effect of organic manures on viable microbial count of soil

Treatments	Bacteria (x 10^8 cfu g^{-1})			Fungi (x 10^3 cfu g^{-1})			Actinomycetes (x 10^2 cfu g^{-1})		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
T_1*	140.7	143.7	142.2	3.22	3.16	3.19	2.50	2.71	2.61
T_2	175.0	178.3	176.7	3.42	3.55	3.49	3.15	3.17	3.16
T_3	165.0	167.3	166.2	3.45	3.67	3.56	2.79	2.79	2.79
T_4	202.7	204.0	203.3	4.16	4.42	4.29	3.66	3.71	3.69
T_5	173.7	173.3	173.5	3.67	3.78	3.72	2.86	2.87	2.86
T_6	159.0	157.7	158.3	3.56	3.56	3.56	2.77	2.74	2.76
T_7	188.0	194.7	191.3	4.08	4.15	4.12	3.18	3.20	3.19
T_8	166.3	168.7	167.5	3.88	3.73	3.80	2.85	2.92	2.89
T_9	154.3	157.3	155.8	3.04	3.42	3.23	2.64	2.67	2.65
T_{10}	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*	

*T_1: 100% recommended dose of nutrients (RDN), T_2: 90% RDN + *Panchgavya* @ 5%, T_3: 90% RDN + *jeevamrut* @ 5%, T_4: 90% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_5: 80% RDN + *Panchgavya* @ 5%, T_6: 80% RDN + *jeevamrut* @ 5%, T_7: 80% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_8: 70% RDN + *Panchgavya* @ 5%, T_9: 70% RDN + *jeevamrut* @ 5%, T_{10}: 70% RDN + *panchagavya* (5%) + *jeevamrut* (5%)

microbial growth. These observations are supported by a large-scale meta-analysis that found manure applications increased microbial biomass carbon by approximately 40% compared to chemical fertilizers, particularly under organic systems (Ren *et al.*, 2019). Similarly, long-term use of manure significantly enhanced microbial community activity and diversity, contributing to greater soil carbon cycling and microbial biomass (Francioli *et al*., 2016).

These results highlight that microbial enhancement through organic inputs is not merely a secondary benefit but a central mechanism by which soil health and productivity are sustained. By increasing populations of bacteria, fungi, and actinomycetes, treatments like T_4 contribute to the development of a biologically enriched soil environment that can respond dynamically to nutrient demands and environmental stress. Rather than acting as passive nutrient carriers, these microorganisms actively participate in decomposing organic matter, releasing nutrients, and forming symbiotic relationships with plant roots. The ability of organic formulations to enrich microbial communities suggests their strategic value in regenerating soil systems that have been degraded by chemical-intensive practices, thus supporting a more adaptive and self-sustaining model of agriculture through organic farming.

c) **Soil enzymes**

The pooled results showed that soil enzyme activities such as dehydrogenase, phosphatase, and urease were significantly influenced by the application of different organic treatments (Table 11). T_4 (90% RDN + *panchagavya* @ 5% + *jeevamrut* @ 5%) recorded the highest activity levels for all three enzymes: dehydrogenase (4.80 mg TPF h^{-1} g^{-1} soil), phosphatase (30.98 µmol PNP h^{-1} g^{-1} soil), and urease (0.29 mg NH_4^+ g^{-1} soil). In contrast, the lowest enzyme activities were consistently observed in T_1, which recorded 2.91 mg TPF h^{-1} g^{-1} soil for dehydrogenase, 19.21 µmol PNP h^{-1} g^{-1} soil for phosphatase, and 0.16 mg NH_4^+ g^{-1} soil for urease.

The enhanced enzyme activities observed under T_4 treatments suggest enhanced microbial functioning and organic matter turnover in the soil. Dehydrogenase activity, often regarded as a general indicator of microbial oxidative metabolism, was highest where both organic manure and microbial stimulants were combined, indicating enhanced microbial respiration and energy flow through soil biota. Similarly, the increase in phosphatase and urease activities suggests improved organic phosphorus mineralization and nitrogen cycling, respectively.

These findings are in agreement with recent

Table 10. 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*	44.91	47.35	46.13
T_2	55.38	57.20	56.29
T_3	49.41	51.08	50.24
T_4	63.52	66.52	65.02
T_5	56.08	57.70	56.89
T_6	51.93	53.82	52.87
T_7	61.12	62.04	61.58
T_8	54.22	55.55	54.88
T_9	47.58	48.57	48.08
T_{10}	61.04	62.08	61.56
CD $_{(p\leq0.05)}$	*1.54*	*2.98*	

*T_1: 100% recommended dose of nutrients (RDN), T_2: 90% RDN + *Panchgavya* @ 5%, T_3: 90% RDN + *jeevamrut* @ 5%, T_4: 90% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_5: 80% RDN + *Panchgavya* @ 5%, T_6: 80% RDN + *jeevamrut* @ 5%, T_7: 80% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_8: 70% RDN + *Panchgavya* @ 5%, T_9: 70% RDN + *jeevamrut* @ 5%, T_{10}: 70% RDN + *panchagavya* (5%) + *jeevamrut* (5%)

studies demonstrating increased enzyme activities due to the application of FYM and organic liquid formulations. The integration of FYM with other organic sources like neem cake and vermicompost has been shown to significantly enhance urease, dehydrogenase, and acid phosphatase activities in banana and black pepper cropping systems (Jadhav *et al*., 2016). Similarly, long-term application of FYM alone or in combination with fertilizers has consistently improved soil urease, amidase, and protease activities in tropical cropping systems (Priyadarshini *et al.,* 2019), emphasizing the strong link between organic nutrient inputs and the stimulation of functional microbial communities.

This indicates that in organic systems, it's not just the presence of microbes that matters, but their biochemical activity that drives nutrient availability, root interaction, and soil regeneration. Thus, enzyme assays serve as critical biomarkers for evaluating the success of sustainable soil management practices.

CONCLUSION

This study demonstrated the substantial benefits of integrating organic manures with liquid bioformulations on okra cultivation and soil microbial health. Among the ten treatments evaluated, the combination of 90% recommended dose of nutrients (RDN) with 5% *panchagavya* and 5% *jeevamrut* (T_4) consistently outperformed all others. It led to the highest improvements in plant growth parameters, fruit yield and quality, nutrient content, and total nutrient uptake, as well as enhanced soil microbial populations and enzyme activities.

These findings highlight the potential of well-designed organic nutrient strategies to serve as effective alternatives to conventional chemical inputs. For farmers, adopting such integrated organic formulations can lead to improved crop productivity and better produce quality, while also reducing input costs and chemical dependence. The observed improvements in soil biological health indicate long-term benefits for soil fertility, making such approaches both agronomically and economically sustainable.

From a policy perspective, this study supports the development of region-specific organic packages that promote the use of bioformulations like *panchagavya* and *jeevamrut* alongside farmyard or compost-based manures. Government support through extension services, training, and subsidy frameworks can help farmers transition toward low-cost, high-efficiency organic systems.

In conclusion, the use of integrated organic nutrient management, particularly the T_4 combination, offers a scientifically validated and environmentally

Table 11. 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^*	2.94	2.88	2.91	19.35	19.07	19.21	0.16	0.16	0.16
T_2	4.18	4.20	4.19	23.02	23.37	23.20	0.23	0.24	0.23
T_3	4.09	4.24	4.17	25.07	26.03	25.55	0.24	0.25	0.24
T_4	4.87	4.73	4.80	31.35	30.60	30.98	0.30	0.29	0.29
T_5	3.89	3.92	3.91	26.17	25.79	25.98	0.20	0.21	0.20
T_6	4.06	4.10	4.08	20.60	20.57	20.58	0.18	0.19	0.18
T_7	4.24	4.35	4.30	27.36	28.03	27.70	0.26	0.25	0.25
T_8	3.31	3.40	3.36	20.49	20.23	20.36	0.17	0.18	0.17
T_9	4.26	4.33	4.29	27.37	28.04	27.71	0.25	0.23	0.24
T_{10}	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
CD $_{(p\leq0.05)}$	*0.11*	*0.19*		*1.00*	*0.81*		*0.01*	*0.02*	

*T_1: 100% recommended dose of nutrients (RDN), T_2: 90% RDN + *Panchgavya* @ 5%, T_3: 90% RDN + *jeevamrut* @ 5%, T_4: 90% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_5: 80% RDN + *Panchgavya* @ 5%, T_6: 80% RDN + *jeevamrut* @ 5%, T_7: 80% RDN + *panchagavya* (5%) + *jeevamrut* (5%), T_8: 70% RDN + *Panchgavya* @ 5%, T_9: 70% RDN + *jeevamrut* @ 5%, T_{10}: 70% RDN + *panchagavya* (5%) + *jeevamrut* (5%)

sustainable solution for enhancing crop productivity, maintaining soil health, and advancing the goals of climate-resilient and chemical-free agriculture.

Acknowledgement

The authors are thankful Dr. Y S Parmar University of Horticulture and Foresty, Nauni, Solan (H.P.), for providing the infrastructural support.

Conflicts of interest

All authors declare that they have no conflicts of interest.

Authors' contribution

Conceptualization and designing of research work (FL, RK); Execution of field/lab experiments and data collection (FL, GR); Analysis of data and interpretation (FL, AS, VSS); Preparation of manuscript (FL, AS, NL).

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