

Residual Soil Fertility and Yield of Okra as Affected by Bio-inoculants and Bio-organic Nutrient Sources

ABSTRACT

Over the course of two kharif seasons in 2020 and 2021, a study was conducted to explore the impact of bi-inoculants (*Pseudomonas fluorescens* and *Pseudomonas lactis*) and bio-organic nutrient sources (farmyard manure, vermicompost, Beejamrit and Jeevamrit) over the fruit yield and residual soil fertility of okra in the Entisols of Himachal Pradesh. The study was structured around seventeen treatments with different combinations of bio-inoculants, bio-formulations and nutrient sources. The investigation revealed that minimum soil pH (6.96), maximum soil organic carbon (0.76 %), available nitrogen (259.36 kg/ha) and available phosphorus (26.98 kg/ha) were obtained with treatment T₁₆ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + *Pseudomonas fluorescens*]. The maximum soil electrical conductivity (0.208 dSm⁻¹) and available potassium (174.65 kg/ha) was obtained in treatment T₁₇ [Recommended Dose of Fertilizer (78N:50P:54K kg/ha)]. The highest gross income (₹2,58,760 /ha), net income (₹1,60,620 /ha) were observed in treatment T₁₆ [FYM (50 q/ha) + Vermicompost (25q/ha) + Jeevamrit + *Pseudomonas fluorescens*] and the highest benefit: cost ratio (1.69) was observed in treatment T₁₀ [Jeevamrit + *Pseudomonas fluorescens*]. Therefore, it is evident that using bio-organic nutrients such as farmyard manure, vermicompost, and Jeevamrit, in conjunction with the bacterium *Pseudomonas fluorescens*, is advantageous for enhancing the residual fertility of the soil and achieving sustainable cultivation of okra, while also allowing for a complete savings of 100% on fertilizers.

Keywords: Bio-inoculants; jeevamrit; okra; residual soil fertility; vermicompost.

1. INTRODUCTION

Okra is a popular vegetable grown as an annual crop in tropical and subtropical regions of the world and is believed to have originated in Tropical Africa. Okra is a good source of iodine, vitamins and other vital minerals. Okra requires a substantial amount of nutrients, and without the proper nutrient levels, it may exhibit deficiency symptoms or suffer from 'hidden hunger' that hampers its growth [1]. While chemical fertilizers are widely used and favoured by farmers due to their immediate nutrient release and accessibility [2,3,4], they maintain high crop yields. However, the persistent and excessive application of these fertilizers has led to numerous environmental issues, such as pollution of air and water, and degradation of soil health. This includes a reduction in the soil's natural organic carbon, increased soil salinity, and altered pH levels, all of which can ultimately impact crop yields negatively [5,6,7,8,9].

The overapplication of chemical fertilizers in pursuit of higher crop yields has led to detrimental effects on soil health, including micronutrient deficiencies, lack of desirable plant

traits, and nutrient imbalances, all contributing to reduced agricultural output. Furthermore, the intensive use of these chemicals in farming has been linked to several environmental issues, such as increased soil salinity, accumulation of heavy metals, eutrophication of water bodies, and a rise in nitrate levels. Additionally, this practice contributes to air pollution through the release of various nitrogen oxides (NO, N₂O, and NO₂) due to excessive fertilization [10]. Therefore, to cure the ills of chemical agriculture, it is necessary to minimize the application of chemical inputs by substituting them with organic nutrient sources like farmyard manure, vermicompost, jeevamrit, beejamrit and plant growth promoting rhizobacteria etc. The use of organic inputs is an eco-friendly practice where locally available inputs are used to improve soil health. These inputs work in synchronization with nature and create a balance between crop production, environment and human health [11].

Organic nutrient sources play an important role in the maintenance of soil physical, chemical and biological properties for sustaining better plant growth. Okra responds very well to organic manure application and is efficient in fertilizer use

which is the key to its higher growth and yield. Farmyard manure is an important source of N, P and K and its addition to the soil, increases the available P and exchangeable K, Ca and Mg content [12]. The utilization of decomposed farmyard manure enhances the physical structure of the soil, boosts its fertility, and contributes organic matter. Vermicompost, a type of organic fertilizer, is rich in nitrogen, phosphorus, potassium, and various micronutrients vital for plant growth [13]. The use of bio-organic materials leads to better structural integrity and reduced soil density by augmenting the organic content and achieving a balance between small and large soil pores. Organic fertilizers also enhance the soil's ability to retain moisture, its rate of water absorption, and its water conductivity [14,15]. Certain bio-inoculants improve seed germination, plant development, and agricultural yield by residing in the root zone and promoting growth through processes such as nitrogen fixation, nutrient solubilization (phosphorus, potassium), and siderophore production [16]. These bio-inoculants also produce plant growth regulators like indoleacetic acid, gibberellic acid, and cytokinins, which modify the root architecture and support plant growth [17]. Jeevamrit is one of the most important components for nutrient management. Application of jeevamrit increased the activity of microbes by solubilization and also enhanced nutrient uptake. Treatment of seed with beejamrit resulted in improvement in seed germination, seedling length and seed vigour. Organic agriculture, which incorporates these organic inputs, is a comprehensive approach and management system that benefits both the agricultural ecosystem and human health [18]. In light of these considerations, the current research was designed and executed to assess the impact of bio-inoculants (*Pseudomonas fluorescens* and *Pseudomonas lactis*) and bio-organic nutrient sources (farmyard manure, vermicompost, Beejamrit, and Jeevamrit) on the remaining soil fertility and the yield of okra fruit in the Entisols of Himachal Pradesh.

2. MATERIALS AND METHODS

2.1 Experimental Site

During the kharif seasons of 2020 and 2021, a field study on okra was carried out at the College of Horticulture and Forestry's research farm in Hamirpur, Himachal Pradesh, located at a latitude of 31° 41'47.6" N and a longitude of 76° 28'06.3" E, and an elevation of 650 meters above sea level. The chosen location had been

free from chemical fertilizers and synthetic agrochemicals for five years prior to the start of the experiment. The Experiment comprised of 18 treatments viz., T₀ [Control], T₁ [FYM (50 q/ha) + Vermicompost (25 q/ha)], T₂ [Beejamrit + Jeevamrit], T₃ [Cow urine + Jeevamrit], T₄ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit], T₅ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Beejamrit + Jeevamrit], T₆ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Cow urine + Jeevamrit], T₇ [FYM (50 q/ha) + Vermicompost (25 q/ha) + *Pseudomonas lactis*], T₈ [FYM (50 q/ha) + Vermicompost (25 q/ha) + *Pseudomonas fluorescens*], T₉ [Jeevamrit + *Pseudomonas lactis*], T₁₀ [Jeevamrit + *Pseudomonas fluorescens*], T₁₁ [FYM (100 q/ha) + Jeevamrit + *Pseudomonas lactis*], T₁₂ [FYM (100 q/ha) + Jeevamrit + *Pseudomonas fluorescens*], T₁₃ [Vermicompost (50 q/ha) + Jeevamrit + *Pseudomonas lactis*], T₁₄ [Vermicompost (50 q/ha) + Jeevamrit + *Pseudomonas fluorescens*], T₁₅ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + *Pseudomonas lactis*], T₁₆ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + *Pseudomonas fluorescens*] and T₁₇ [Recommended dose of fertilizer (78N:50P:54K kg/ha)]. The soil at the farm is categorized as "non-calcic brown soils," which show signs of profile development and belong to the Entisols soil order. The region's climate is classified as subtropical, with average high and low temperatures of 35.9°C and 20.1°C, respectively, and an average annual rainfall of 1225 mm. Approximately 82% of the year's total rainfall occurred during the main growing season for crops, from June to October. The soil at the research location is classified as sandy clay loam, with a composition of 58.60% sand, 14.60% silt, and 26.80% clay. It has a pH of 7.03, an electrical conductivity (EC) of 0.209 dS/m, and contains 0.68% organic carbon (OC). Prior to initiating the experiment, the soil was tested and found to contain 196.94 kg/ha of nitrogen, 14.67 kg/ha of phosphorus, and 156.66 kg/ha of potassium available for plant use.

2.2 Experimental Design and Crop Management

Beejamrit: To prepare Beejamrit, begin by placing 5 kg of fresh cow dung inside a cloth and securing it with a rope. Submerge the cloth-wrapped cow dung in a bucket filled with 20 liters of water for up to 12 hours. In a separate container, mix 50 grams of lime with one liter of water and leave it overnight. The following morning, press the cow dung bundle into the same water three times in succession to extract

its full potency. Incorporate a handful of soil from the field's edge into this mixture and mix thoroughly. Finally, add 5 liters of cow urine and the lime solution, stirring well. The Beejamrit is now prepared and ready to be used according to the treatment schedule.

Jeevamrit: Jeevamrit is created by combining 10 kg of fresh cow dung, 10 liters of cow urine from a local breed, 1 to 2 kg of jaggery, 1 to 2 kg of gram flour, and a handful of fertile soil in a plastic drum. This concoction is then mixed thoroughly. For the next 5 to 7 days, it should be stirred for at least ten minutes twice daily, moving in a clockwise direction with a wooden stick. Following this, 200 liters of water are added. Once these steps are completed, the Jeevamrit is ready to be used according to the specified treatment plan.

2.3 Soil Sampling and Analysis

At the conclusion of a two-year experiment, soil samples were collected from the top 15 cm of the treatment plots. These samples were air-dried, sieved through a 0.2 cm mesh, and stored in cloth bags for subsequent chemical analysis. The parameters assessed included soil pH, electrical conductivity (EC), organic carbon content, and the availability of nitrogen (N), phosphorus (P), and potassium (K). Soil pH and EC were measured using a digital pH meter and an electrical conductivity meter, respectively. Organic carbon content was determined using the Chromic and Titration method proposed by Walkley and Black [19]. The Alkaline Potassium Permanganate Method was employed to determine available N, while P levels were measured using the method outlined by Olsen [20]. Available K was quantified using the Normal Neutral Ammonium Acetate Method [21]. The mean data values underwent analysis of variance following the approach described by Gomez and Gomez [22] for a Randomized Complete Block Design.

2.4 Statistical and Economic Analysis

The statistical analysis of soil and plant samples involved pooling the data, following the approach recommended by Gomez and Gomez [22]. This analysis aimed to determine the impact of treatments on various plant and soil parameters. Additionally, an economic assessment was conducted, considering the costs associated with different treatments and the market price of the produce. The benefit-to-cost ratio (B/C ratio) was

calculated by dividing the value of marketable produce by the total cost of cultivation.

3. RESULTS AND DISCUSSION

3.1 pH of Soil

The soil pH was analyzed after harvesting of the crop, and the result tabulated in Table 1. Maximum soil pH (7.07) was obtained by the treatment T₃ Cowurine + Jeevamrit and minimum soil pH (6.96) was obtained with treatment T₁₆ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + *Pseudomonas fluorescens*]. The soil pH slightly decreased with the application of *Pseudomonas fluorescens* due to reason that it might have the ability to make insoluble phosphorus available to the plants. The solubilization effect is directly related to production of organic acids, which lower the soil pH [23].

3.2 Electrical Conductivity of Soil (dSm⁻¹)

The measurement of electrical conductivity is important, as it provides information related to the concentration of soluble salts present in the soil. The data revealed that the maximum soil EC (0.208 dSm⁻¹) was obtained in treatment T₁₇ [Recommended Dose of Fertilizer (78N:50P:54K kg/ha)] after harvesting the crop. Whereas, the minimum soil EC (0.187 dSm⁻¹) was found in treatment T₁₂ [FYM (100 q/ha) + Jeevamrit + *Pseudomonas fluorescens*] which was found statistically at par with treatment T₁₂ [FYM (100 q/ha) + Jeevamrit + *Pseudomonas lactis*] recording 0.188 dSm⁻¹ electrical conductivity of soil (Table 1). These findings are quite similar to the findings of Lakra et al. [24].

3.3 Soil Organic Carbon (%)

The maximum soil organic carbon (0.76 %) was recorded in treatment T₁₆ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + *Pseudomonas fluorescens*] which was statistically at par with treatment T₁₅ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + *Pseudomonas lactis*] recording 0.75 % soil organic carbon. While, minimum soil organic carbon (0.61 %) was recorded in treatment T₀ [Control] after harvesting of the crop (Table 1). This may be due to an increase in microbial activities in the rhizosphere which decomposed organic manures and also helped in fixing the unavailable form of mineral nutrients into available forms in the soil and improving organic

carbon level. Similar findings are reported by [25,23].

3.4 Available Nitrogen (kg/ha)

The data for available nitrogen is presented in Table 2. Maximum available nitrogen (259.36 kg/ha) was recorded in treatment T₁₆ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + *Pseudomonas fluorescens*] and minimum (188.74 kg/ha) in T₀ [Control] after harvesting of the crop. Overall mean for available nitrogen was 231.75 kg/ha. Fixation of atmospheric nitrogen by *Pseudomonas fluorescens* in rhizosphere and mineralization of organic manures might have increased the nitrogen and enhanced the uptake of nitrogen in plants. These results are in line with the finding of Brar et al. [25].

3.5 Available Phosphorus (kg/ha)

Maximum available phosphorus (26.98 kg/ha) was recorded in treatment T₁₆ [FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + *Pseudomonas fluorescens*] and minimum (14.50 kg/ha) in treatment T₀ [Control] after harvesting of the crop (Table 2). An increase in available phosphorus in soil over the initial value, indicated that addition of organic manures and *Pseudomonas fluorescens*, increased the solubility of phosphorus by producing certain organic acids and thereby increased the available phosphorus in the soil. Similar results were recorded by [25,23].

Table 1. Effect of plant growth promoting rhizobacteria and organic manures on pH, EC (dSm⁻¹) and organic carbon (%) of soil

Treatment Code	Treatment Details	pH of soil	EC of soil (dSm⁻¹)	Organic carbon of soil (%)
T ₁	FYM (50 q/ha) + Vermicompost (25 q/ha)	7.04	0.204	0.65
T ₂	Beejamrit + Jeevamrit	7.05	0.205	0.63
T ₃	Cowurine + Jeevamrit	7.07	0.198	0.65
T ₄	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit	7.03	0.192	0.65
T ₅	FYM (50 q/ha) + Vermicompost (25 q/ha) + Beejamrit + Jeevamrit	7.04	0.206	0.64
T ₆	FYM (50 q/ha) + Vermicompost (25 q/ha) + Cowurine + Jeevamrit	7.03	0.198	0.65
T ₇	FYM (50 q/ha) + Vermicompost (25 q/ha) + <i>Pseudomonas lactis</i>	7.02	0.203	0.72
T ₈	FYM (50 q/ha) + Vermicompost (25 q/ha) + <i>Pseudomonas fluorescens</i>	7.03	0.196	0.73
T ₉	Jeevamrit + <i>Pseudomonas lactis</i>	7.01	0.201	0.72
T ₁₀	Jeevamrit + <i>Pseudomonas fluorescens</i>	6.98	0.195	0.71
T ₁₁	FYM (100 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	7.02	0.188	0.73
T ₁₂	FYM (100 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	6.97	0.187	0.74
T ₁₃	Vermicompost (50 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	7.03	0.199	0.71
T ₁₄	Vermicompost (50 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	6.99	0.197	0.72
T ₁₅	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	7.01	0.202	0.75
T ₁₆	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	6.96	0.201	0.76
T ₁₇	Recommended dose of fertilizer (78N:50P:54K kg/ha)	7.04	0.208	0.70
	Mean	7.02	0.198	0.69
	CD_(0.05)	0.01	0.001	0.01
	SE(m)	0.01	0.002	0.00
	C.V	0.45	1.54	1.49

Table 2. Effect of plant growth promoting rhizobacteria and organic manures on available N (kg/ha), P (kg/ha) and K (kg/ha) in soil

Treatment Code	Treatment Details	Available N in soil (kg/ha)	Available P in soil (kg/ha)	Available K in soil (kg/ha)
T ₀	Control	188.74	14.50	141.55
T ₁	FYM (50 q/ha) + Vermicompost (25 q/ha)	208.64	17.33	148.75
T ₂	Beejamrit + Jeevamrit	207.90	16.90	148.03
T ₃	Cowurine + Jeevamrit	205.98	16.45	146.07
T ₄	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit	206.51	17.04	149.96
T ₅	FYM (50 q/ha) + Vermicompost (25 q/ha) + Beejamrit + Jeevamrit	235.46	19.70	163.41
T ₆	FYM (50 q/ha) + Vermicompost (25 q/ha) + Cowurine + Jeevamrit	225.23	19.87	161.76
T ₇	FYM (50 q/ha) + Vermicompost (25 q/ha) + <i>Pseudomonas lactis</i>	242.13	19.55	160.83
T ₈	FYM (50 q/ha) + Vermicompost (25 q/ha) + <i>Pseudomonas fluorescens</i>	246.36	18.96	164.96
T ₉	Jeevamrit + <i>Pseudomonas lactis</i>	213.66	22.50	150.78
T ₁₀	Jeevamrit + <i>Pseudomonas fluorescens</i>	238.21	22.08	159.73
T ₁₁	FYM (100 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	248.95	21.34	162.85
T ₁₂	FYM (100 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	255.54	22.52	167.29
T ₁₃	Vermicompost (50 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	236.94	21.01	163.68
T ₁₄	Vermicompost (50 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	244.44	22.72	166.95
T ₁₅	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	253.44	22.07	164.84
T ₁₆	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	259.36	26.98	170.27
T ₁₇	Recommended dose of fertilizer (78N:50P:54K kg/ha)	254.03	23.93	174.65
	Mean	231.75	20.30	159.24
	CD_(0.05)	1.21	0.23	0.36
	SE(m)	0.42	0.08	0.12
	C.V	0.31	0.70	0.13

Table 3. Effect of plant growth promoting rhizobacteria and organic manures on economics of okra cultivation

Treatment Code	Treatment Details	Total fruit yield (q/ha)	Total cost of Cultivation (₹/ha)	Gross Income (₹/ha)	Net Income (₹/ha)	B:C ratio
T ₀	Control	50.05	45,140	1,00,100	54,960	1.21
T ₁	FYM (50 q/ha) + Vermicompost (25 q/ha)	86.41	79,140	1,72,820	93,680	1.18
T ₂	Beejamrit + Jeevamrit	85.00	63,945	1,70,000	1,06,055	1.65
T ₃	Cowurine + Jeevamrit	82.16	63,640	1,64,320	1,00,680	1.58
T ₄	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit	81.22	97,640	1,62,440	64,800	0.66
T ₅	FYM (50 q/ha) + Vermicompost (25 q/ha) + Beejamrit + Jeevamrit	86.41	97,945	1,72,820	74,875	0.76
T ₆	FYM (50 q/ha) + Vermicompost (25 q/ha) + Cowurine + Jeevamrit	83.11	97,640	1,66,220	68,580	0.70
T ₇	FYM (50 q/ha) + Vermicompost (25 q/ha) + <i>Pseudomonas lactis</i>	89.25	79,540	1,78,500	98,960	1.24
T ₈	FYM (50 q/ha) + Vermicompost (25 q/ha) + <i>Pseudomonas fluorescens</i>	93.97	79,640	1,87,940	1,08,300	1.35
T ₉	Jeevamrit + <i>Pseudomonas lactis</i>	85.94	64,040	1,71,880	1,07,840	1.68
T ₁₀	Jeevamrit + <i>Pseudomonas fluorescens</i>	86.41	64,140	1,72,820	1,08,680	1.69
T ₁₁	FYM (100 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	89.72	82,040	1,79,440	97,400	1.18
T ₁₂	FYM (100 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	103.41	82,140	2,06,820	1,24,680	1.51
T ₁₃	Vermicompost (50 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	96.33	1,14,040	1,92,660	78,620	0.68
T ₁₄	Vermicompost (50 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	103.88	1,14,140	2,07,760	93,620	0.82
T ₁₅	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + <i>Pseudomonas lactis</i>	127.02	98,040	2,54,040	1,56,000	1.59
T ₁₆	FYM (50 q/ha) + Vermicompost (25 q/ha) + Jeevamrit + <i>Pseudomonas fluorescens</i>	129.38	98,140	2,58,760	1,60,620	1.63
T ₁₇	Recommended dose of fertilizer (78N:50P:54K kg/ha)	94.91	71,051	1,89,820	1,18,769	1.67

3.6 Available Potassium (kg/ha)

Maximum available potassium (174.65 kg/ha) was recorded in treatment T₁₇ [Recommended Dose of Fertilizer (78N:50P:54K kg/ha)] and minimum (141.55 kg/ha) was recorded in T₀ [Control] after harvesting of crop (Table 2). Greater availability of nutrients from inorganic sources might have increased available potassium in soil. Similar results were observed by Lakra et al. [24,26].

3.7 Economics of Okra Cultivation

Data for economics of okra cultivation is presented in Table 3. Maximum gross income of (₹ 2,58,760 /ha) was obtained by treatment T₁₆ and minimum (₹ 1,00,100 /ha) was obtained with treatment T₀. Maximum net income (₹ 1,60,620 /ha) was recorded by treatment T₁₆ while, minimum (₹54,960 /ha) was recorded by treatment T₀. Highest B:C ratio (1.69) was recorded by treatment T₁₀ whereas, lowest B:C ratio (0.66) was recorded by treatment T₄.

4. CONCLUSION

Treatment T₁₆ was found superior for most of soil parameters Highest gross income (₹2,58,760 /ha), net income (₹1,60,620 /ha) were observed in treatment T₁₆ and highest benefit:cost ratio (1.69) was observed in treatment T₁₀. Hence, it can be concluded that, application of organic manures viz., FYM, vermicompost and jeevamrit along with *Pseudomonas fluorescens* improves the soil available nutrients and beneficial for improving residual soil fertility, nutrient uptake, and sustainable okra production with 100% net saving of fertilizers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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