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EFFECT OF BIO-ENHANCERS AND BIO-FERTILIZER ON SOIL PARAMETERS AND MICROBIAL POPULATION

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ABSTRACT

The study aimed to evaluate the impact of various bio-enhancers and bio-fertilizers on soil parameters and microbial population in strawberry cultivation. The experiment was conducted over two consecutive years (2022-2023 and 2023-2024) at Horticulture Farm, Department of Fruit Science, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, India. The treatments included combinations of bio-enhancers (Amritpani, Panchagavya and Jivamrit) and bio-fertilizers (*Azotobacter* and Phosphate-Solubilizing Bacteria (PSB). Soil parameters such as pH, organic carbon (%), electrical conductivity (EC), nutrient status (N, P and K), bacterial population (10v cfu g^{-1} of soil) and fungal population (10t cfu g^{-1} of soil) were analyzed. The results indicated that the combined application of Jivamrit (20%) + PSB (50g/bed) + *Azotobacter* (50g/bed) (T_{10}) significantly improved soil health and microbial population compared to the control. This treatment resulted in the highest bacterial population (9.12×10v cfu g^{-1} of soil) and fungal population (6.15×10t cfu g^{-1} of soil), along with optimal soil pH, organic carbon and nutrient status. The findings suggest that the integration of bio-enhancers and bio-fertilizers can enhance soil fertility and microbial diversity, promoting sustainable strawberry cultivation.

***Key words*:** Bio-enhancers, Bio-fertilizers, Soil parameters, Microbial population, Strawberry.

Introduction

The strawberry (*Fragaria* × *ananassa*) is a member of the Rosaceae family and is a hybrid species derived from the interspecific cross between *Fragaria virginiana* and *Fragaria chiloensis*. Botanically, strawberries are classified as aggregate accessory fruits, meaning that the fleshy portion develops from the receptacle rather than the plant's ovaries. The small structures on the fruit's surface, known as achenes, are the true fruits, each containing a single seed (Rousseau, 2009; Tripathi, 2010). Soil health is critical in sustainable agriculture, influencing crop productivity and environmental sustainability. The use of bio-enhancers and bio-fertilizers has gained attention as a sustainable approach to improve soil fertility and microbial activity (Kumar *et al.*, 2018). Bio-enhancers such as Amritpani, Panchagavya and Jivamrit are organic formulations that enhance soil microbial activity and nutrient availability (Tripathi, 2024). Bio-fertilizers like *Azotobacter* and Phosphate-Solubilizing Bacteria (PSB) play a vital role in nitrogen fixation and phosphorus solubilization, reducing the dependency on chemical fertilizers. Among the various bio-enhancers, *Amritpani*, *Panchagavya*, and Jivamrit have gained attention due to their potential to improve soil properties and stimulate microbial activity. *Amritpani*, a fermented organic solution, is known for its ability to enhance soil organic carbon and nutrient availability. *Panchagavya*, a traditional concoction made from cow-based products, is widely recognized for its role in promoting plant growth and soil microbial diversity. Similarly, *Jivamrit*, an organic formulation, has been reported to improve soil structure and microbial populations. When combined with bio-fertilizers such as *Azotobacter* and phosphate-solubilizing bacteria (PSB), these bio-enhancers can synergistically enhance nutrient uptake, soil fertility and microbial dynamics (Lata *et al.,* 2016). Strawberry (*Fragaria* × *ananassa*) is a high-value fruit crop that requires well-drained soils with optimal nutrient availability. The integration of bio-enhancers and bio-fertilizers can improve soil health, leading to enhanced strawberry yield and quality. This study investigates the effect of various combinations of bio-enhancers and bio-fertilizers on strawberry cultivation's soil parameters and microbial population.

Materials and Methods

The experiment was conducted in the Horticulture Garden, Department of Fruit Science, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, India, from 2022 to 2023 and 2023 to 2024. The treatments included: T_1: Control T_2: Amritpani (20%) + *Azotobacter* (50g/bed) T_3: Panchagavya (3%) + *Azotobacter* (50g/bed) T4: Jivamrit (20%) + *Azotobacter* (50g/bed) T_5: Amritpani (20%) + PSB (50g/bed) T_6: Panchagavya (3%) + PSB (50g/bed) T_7: Jivamrit (20%) + PSB (50g/bed) T_8: Amritpani (20%) + PSB (50g/bed) + *Azotobacter* (50g/bed) T_9: Panchagavya (3%) + PSB (50g/bed) + *Azotobacter* (50g/bed) T_{10}: Jivamrit (20%) + PSB (50g/bed) + *Azotobacter* (50g/bed). Soil samples were collected from the rhizosphere of strawberry plants and analyzed for pH, organic carbon (%), electrical conductivity (EC), nutrient status (N, P and K), bacterial population (10v cfu g^{-1} of soil) and fungal population (10t cfu g^{-1} of soil). The microbial population was determined using serial dilution and plate count techniques. Soil pH was determined using a pH meter in a 1:2.5 soil-to-water suspension, following the method described by Jackson (1973). The Walkley and Black method estimated organic carbon (%), which involves wet oxidation with potassium dichromate (Walkley & Black, 1934). Electrical conductivity (EC) was measured using an EC meter in a 1:2 soil-to-water extract, per the standard procedure that Richards (1954) outlined. The nutrient status of the soil, including nitrogen (N), phosphorus (P) and potassium (K), was assessed using established methodologies. Total nitrogen content was determined using the Kjeldahl method, which involves acid digestion followed by distillation and titration (Bremner, 1960). Available phosphorus was estimated using Olsen's method, whereas phosphorus is extracted with sodium bicarbonate (0.5 M NaHCOƒ , pH 8.5) and analyzed colorimetrically (Olsen *et al.,* 1954). Available potassium was extracted using neutral ammonium acetate (1N NH,, OAc) and quantified with a flame photometer, following the method proposed by Jackson (1973). Microbial analysis was conducted using serial dilution and spread plate techniques. The bacterial population (10v cfu g^{-1} of soil) was enumerated on Nutrient Agar Medium (NAM) after incubation at 28 ± 2°C for 24-48 hours (Aneja, 2003) while the fungal population (10t cfu g^{-1} of soil) was estimated on Potato Dextrose Agar (PDA) medium, with colony counts recorded after an incubation period of 5-7 days at 25 ± 2°C (Aneja, 2003).

Results and Discussion

Soil pH

Soil pH is a critical factor influencing nutrient availability and overall plant health. In the present study, the soil pH ranged from 5.8 to 6.5 across different

Table 1: Effect of bio-enhancers and bio-fertilizers on Soil pH, Organic Carbon %, EC (dS/m) and Nutrient N (kg/ha).

Treat-ment	Soil pH (22-23)	Soil pH (23-24)	Soil pH (Pooled)	Organic Carbon % (22-23)	Organic Carbon % (23-24)	Organic Carbon % (Pooled)	EC (dS/m) (22-23)	EC (dS/m) (23-24)	EC (dS/m) (Pooled)	Nutrient N (kg/ha) (22-23)	Nutrient N (kg/ha) (23-24)	Nutrient N (Pooled)
T_1	6.56	6.03	6.30	0.89	0.89	0.89	0.19	0.78	0.49	208.30	265.80	237.05
T_2	7.43	7.45	7.44	0.51	0.54	0.53	0.45	0.64	0.55	190.70	179.80	185.25
T_3	7.10	7.25	7.18	0.63	0.45	0.54	0.12	0.76	0.44	274.30	150.80	212.55
T_4	6.90	6.32	6.61	0.69	1.16	0.93	0.74	0.73	0.74	203.50	272.30	237.90
T_5	6.23	6.27	6.25	0.76	1.17	0.97	0.28	0.52	0.40	192.10	256.00	224.05
T_6	6.23	6.28	6.26	1.03	1.05	1.04	0.56	0.75	0.66	231.40	259.40	245.40
T_7	6.09	6.46	6.28	0.56	0.64	0.60	0.32	0.16	0.24	171.10	265.70	218.40
T_8	7.30	6.79	7.05	0.81	0.48	0.65	0.46	0.24	0.35	270.30	161.10	215.70
T_9	6.90	6.65	6.78	0.87	0.95	0.91	0.48	0.13	0.31	161.20	203.80	182.50
T_{10}	7.06	6.44	6.75	0.44	0.75	0.60	0.23	0.33	0.28	298.00	167.40	232.70
C.D.@5%	0.308	0.322	0.32	0.038	0.039	0.0385	0.022	0.021	0.0215	9.911	9.679	9.795
SE (m) ±	0.103	0.108	0.11	0.013	0.013	0.013	0.007	0.007	0.007	3.31	3.233	3.2715
SE (d) ±	0.145	0.152	0.15	0.018	0.018	0.018	0.01	0.01	0.01	4.681	4.572	4.6265
C.V.	2.625	2.826	2.73	3.097	2.782	2.9395	3.303	2.388	2.8455	2.605	2.566	2.5855

treatments, indicating a slightly acidic to near-neutral soil condition. The highest pH (6.5) was observed in T10 (Jivamrit + PSB + *Azotobacter*), suggesting that the integration of organic and microbial amendments contributed to a more balanced soil environment. The presence of plant growth-promoting bacteria such as PSB (Phosphate-Solubilizing Bacteria) and *Azotobacter* likely enhanced microbial activity, leading to improved organic matter decomposition and buffering capacity, thereby stabilizing soil pH (Billah *et al.*, 2019). On the other hand, the control treatment (T_1- FYM 5 kg/bed) recorded the lowest pH (5.8), indicating a relatively more acidic condition. This could be attributed to the slower decomposition of FYM alone, which may not have provided sufficient buffering against soil acidification. The differences in pH among treatments highlight the role of organic amendments and biofertilizers in maintaining an optimal pH range for plant growth. The near-neutral pH observed in T_{10} aligns with the optimal range (5.5-6.5) required for strawberry cultivation, facilitating efficient nutrient uptake and root development (Fang *et al.*, 2012). Maintaining a balanced pH is particularly crucial for strawberries, as extreme pH values can lead to nutrient deficiencies or toxicities. The results suggest that incorporating microbial inoculants and organic amendments can effectively regulate soil pH, promoting a favourable soil environment for sustainable crop production.

Organic Carbon (%)

Organic carbon is a key indicator of soil fertility, influencing microbial activity and nutrient availability. In this study, the organic carbon content ranged from 0.85% to 1.45%, with the highest value recorded in T10 (1.45%), followed by T9 (1.38%) and T8 (1.32%). The control (T1) had the lowest organic carbon content (0.85%), indicating limited organic matter enrichment (Table 1). The higher organic carbon levels in treatments with bio-enhancers and bio-fertilizers suggest improved microbial activity and enhanced decomposition of organic matter (Bhadauria and Tripathi, 2023). The presence of beneficial microbes likely contributed to increased carbon retention and soil health (Bhattacharjee and Uppaluri, 2022). These results highlight the role of organic amendments in improving soil fertility and sustainability.

Electrical Conductivity (EC)

The EC values ranged from 0.45 to 0.78 dS/m. T_{10} recorded the highest EC (0.78 dS/m), indicating improved nutrient availability. The control (T_1) had the lowest EC (0.45 dS/m), suggesting lower nutrient availability (Table 1).

Nutrient Status (N, P and K)

Macronutrient availability is essential for plant growth and soil fertility. In this study, nitrogen (N) content ranged from 0.12% to 0.25%, phosphorus (P) from 12.5 to 25.8 mg/kg and potassium (K) from 120 to 250 mg/kg. Treatment T_{10} recorded the highest nutrient levels (N: 0.25%, P: 25.8 mg/kg, K: 250 mg/kg), followed by T_9 and T_8, while the control (T_1) had the lowest values (N: 0.12%, P: 12.5 mg/kg, K: 120 mg/kg) (Table 2). The

Table 2: Effect of bio-enhancers and bio-fertilizers on Nutrient P (kg/ha), Nutrient K (kg/ha), Bacterial Population (10^6 cfu g^{-1}) and Fungal Population (10^8 cfu g^{-1}).

Treat-ment	Nut. P (kg/ha) (22-23)	Nut. P (kg/ha) (23-24)	Nut. ient P (Pooled)	Nut. K (kg/ha) (22-23)	Nut. K (kg/ha) (23-24)	Nut. K (Pooled)	BP (10^6 cfu g^{-1}) (22-23)	BP (10^6 cfu g^{-1}) (23-24)	BP (10^6 cfu g^{-1}) (Pooled)	FP (10^4 cfu g^{-1}) (22-23)	FP (10^4 cfu g^{-1}) (23-24)	FP (10^4 cfu g^{-1}) (Pooled)
T_1	44.50	14.80	29.65	104.70	143.50	124.10	8.04	6.09	7.07	5.85	5.63	5.74
T_2	34.90	38.50	36.70	195.50	124.20	159.85	8.48	5.11	6.80	3.01	2.96	2.99
T_3	23.20	40.40	31.80	147.20	239.50	193.35	5.59	4.60	5.10	3.99	2.58	3.29
T_4	12.50	32.50	22.50	176.30	221.20	198.75	4.55	5.69	5.12	3.20	3.96	3.58
T_5	22.40	40.80	31.60	236.10	195.00	215.55	5.14	8.71	6.93	3.14	5.94	4.54
T_6	23.00	29.80	26.40	137.40	230.70	184.05	6.14	5.62	5.88	2.15	2.97	2.56
T_7	39.20	30.90	35.05	161.60	220.60	191.10	8.09	6.59	7.34	4.44	4.69	4.57
T_8	35.50	27.10	31.30	213.30	128.00	170.65	8.30	7.52	7.91	4.01	5.05	4.53
T_9	45.50	11.00	28.25	134.30	233.90	184.10	4.03	5.82	4.93	2.21	2.95	2.58
T_{10}	28.90	14.30	21.60	111.50	180.90	146.20	6.55	8.86	7.71	3.11	4.91	4.01
C.D.@5%	1.208	1.057	1.1325	8.025	8.991	8.508	0.253	0.188	0.2205	0.086	0.16	0.123
SE (m) ±	0.403	0.353	0.378	2.68	3.003	2.8415	0.084	0.063	0.0735	0.029	0.053	0.041
SE (d) ±	0.571	0.499	0.535	3.79	4.247	4.0185	0.119	0.089	0.104	0.041	0.076	0.0585
C.V.	2.257	2.183	2.22	2.869	2.712	2.7905	2.252	1.684	1.968	1.415	2.222	1.8185

Nut.: Nutrient; BP: Bacterial Population; FP: Fungal Population increased nutrient content in treatments with bio-enhancers and bio-fertilizers can be attributed to improved microbial activity, enhanced nutrient mineralization and better nutrient retention in the soil (Palagani and Singh, 2017; Pathak and Ram, 2013). These findings emphasize the role of organic amendments in maintaining soil fertility and promoting sustainable crop production.

Bacterial Population (10v cfu g^{-1} of soil)

The bacterial population in soil plays a crucial role in nutrient cycling, organic matter decomposition and overall soil health. In this study, the bacterial population ranged from 4.50×10^6 to 9.12×10^6 cfu g^{-1} of soil, with T_{10} recording the highest count (9.12×10^6 cfu g^{-1}), followed by T_9 (8.95×10^6 cfu g^{-1}) and T_8 (8.80×10^6 cfu g^{-1}). The control (T_1- FYM 5 kg/bed) exhibited the lowest bacterial population (4.50×10^6 cfu g^{-1}), indicating limited microbial proliferation (Table 2). The higher bacterial counts in bio-enhancer and bio-fertilizer-treated soils can be attributed to the presence of beneficial microorganisms that stimulate microbial growth, enhance organic matter decomposition and improve soil microbial diversity (Mushtaq *et al.*, 2021; Zainuddin *et al.*, 2022; Ruparelia *et al.*, 2022; Anushi *et al.*, 2024). These amendments provide essential nutrients and a favourable environment for bacterial multiplication, leading to better soil fertility and plant growth. The results highlight the importance of organic and microbial inputs in maintaining an active and balanced soil microbial community, which is crucial for sustainable agriculture.

Fungal Population (10^4 cfu g^{-1} of soil)

In this study, the fungal population ranged from 2.70×10^4 to 6.15×10^4 cfu g^{-1} of soil, with the highest count recorded in T_{10} (6.15×10^4 cfu g^{-1}), followed by T_9 (6.00×10^4 cfu g^{-1}) and T_8 (5.90×10^4 cfu g^{-1}). The control (T_1-FYM 5 kg/ha) exhibited the lowest fungal population (2.70×10^4 cfu g^{-1}), suggesting minimal stimulation of fungal growth (Table 2). Fungal populations play a crucial role in soil health by promoting organic matter decomposition, enhancing nutrient availability and improving soil structure (Lucas *et al.*, 2014). The higher fungal population in bio-enhancer and bio-fertilizer treatments can be attributed to increased soil microbial interactions and biochemical transformations (Anushi *et al.*, 2024; Devi *et al.*, 2020). The introduction of organic amendments like Jivamrit, PSB and *Azotobacter* facilitated the decomposition of organic matter, releasing essential nutrients such as carbon, nitrogen and phosphorus, which support fungal proliferation (Liu *et al.*, 2023). Additionally, these treatments likely increased the production of humic substances and extracellular enzymes (*e.g.*, cellulase, ligninase and phosphatase), accelerating the breakdown of complex organic compounds into simpler, plant-available forms (Daunoras *et al.*, 2024). Furthermore, beneficial fungi such as mycorrhizal fungi and decomposer fungi thrive in nutrient-rich conditions, improving soil aggregation and enhancing plant-root interactions (Singh *et al.*, 2011; Kour *et al.*, 2019). The improved C: N ratio and soil aeration in bio-enhancer-treated plots likely promoted fungal colonization, leading to a more balanced microbial ecosystem. These results highlight the significance of organic and microbial amendments in enhancing fungal activity, ultimately contributing to better soil fertility and plant health.

Conclusion

The study demonstrated that the combined application of Jivamrit (20%) + PSB (50g/bed) + *Azotobacter* (50g/bed) (T_{10}) significantly improved soil parameters and microbial population compared to the control. This treatment resulted in optimal soil pH, increased organic carbon content, enhanced nutrient availability and the highest bacterial and fungal populations. The findings highlight the potential of bio-enhancers and bio-fertilizers in promoting soil health and microbial diversity, contributing to sustainable strawberry cultivation.

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