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Comparative study on nutrient uptake and yield of cauliflower in integrated nutrient management involving jeevamrut

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Abstract

The use of integrated nutrient management practices, incorporating fermented liquid organic manures, has proven effective in promoting environmental sustainability, biodiversity, and vegetable production. A field experiment conducted over two consecutive rabi seasons assessed the impact of jeevamrut, a fermented liquid organic manure combined with inorganic nutrients, on cauliflower growth, rhizosphere microbial populations, soil nutrient status, and yield. Ten treatment combinations were evaluated in a randomized complete block design with three replications. The pooled analysis revealed that applying 90% of the recommended dose of nutrients with 5 % jeevamrut at 1.5 L m^{-2} produced optimal results for growth and yield parameters, including number of leaves per plant, plant height (cm), curd compactness (g/cm), gross curd weight (kg), marketable curd weight (g), marketable yield per plot (kg) and soil organic carbon, P, microbial activity and NPK uptake. The highest Benefit-Cost (B:C) ratio was obtained in the treatment where 90% RDN + 5% jeevamrut at 1.0 L m^{-2} was applied. Hence, it can be concluded that the application of jeevamrut combined with RDN has the capability to improve cauliflower plant growth, yield, and yield-contributing traits on a sustainable basis.

Key words: INM, jeevamrut, cauliflower, growth, nutrient uptake

Introduction

Cauliflower (*Brassica oleracea* L. var. *botrytis*), a member of the Brassicaceae family, is descended from *Brassica oleracea* L. var. *sylvestris*, which is still found in western and southern Europe and North Africa. This process of descent involves introgression, mutation, human selection and adaptation. Caulis (stem) and Floris (flower) are the two Latin words that make up the cauliflower. It is cultivated all over the nation for the "Curd," a highly suppressed "pre-floral fleshy apical meristem," which is consumed as a cooked vegetable (Singh *et al.*, 2023).

Rapid urbanization necessitates enhanced vegetable production to meet dietary requirements and eradicate malnutrition. Nutrient management is the most crucial agronomic practice for maintaining vegetable yield and productivity. Due to improved crop yields driven by broad technological adoption, particularly the use of chemical fertilizers, global food production has expanded dramatically over the past century. However, using mineral fertilizers to increase crop productivity and soil fertility often negatively impacts the intricate system of biogeochemical cycles (Howe *et al.*, 2024). Developing low-cost input management approaches is crucial for sustainable crop production in many developing nations, given the exorbitant prices of synthetic fertilizers and their limited availability. The best way to address these issues is through integrated nutrient management, which combines the use of mineral fertilizers and organic manures, including locally available resources, to preserve crop productivity and soil health (Shraddha *et al.*, 2025). While chemical fertilizers add one or two critical elements, organic manure supports mineralization and enhances soil physical and chemical properties. As a result, INM leads to increased crop yield, higher economic returns, and improved soil fertility (Hameedi *et al.*, 2022).

These liquid organic preparations are referred to as "bio-enhancers" in the general sense. These are defined as manures that are created by the prolonged active fermentation of plant and animal waste. These are abundant sources of microbial consortia, macro- and micronutrients, plant growth-promoting compounds, and plant immunity-enhancing compounds that shield plants from various pests and diseases. These could be applied to planting material, such as seeds or seedlings, to improve the breakdown of organic compounds and so improve the fertility, productivity, and vitality of the soil (Somdutt *et al.*, 2023; Biswas *et al.*, 2025; Taha, 2025). According to Shraddha *et al.* (2023), Jeevamrut is a fermented liquid organic preparation that is a rich source of essential macro- and micronutrients, vitamins, minerals, amino acids, and plant growth regulators such as Indole-3-acetic acid and Gibberellic Acid. It enhances microbial activity, which mineralizes the nutrients and makes them available to crops (Bhadu *et al.*, 2021). According to Boraiah *et al.* (2017), jeevamrut is either applied by spray or added to irrigation water at regular intervals to enrich the soil. The effectiveness of using bio-enhancers is evident as it not only improves the environment but also supports the economic stability of the farmers (Vashishat *et al.*, 2024 and Shraddha *et al.*, 2025). It can be hypothesized that the combined application of Jeevamrut and inorganic nutrients will improve cauliflower growth, yield, and soil microbial activity compared with inorganic nutrients alone. Keeping in view, the present investigation was conducted to study the influence of fermented liquid organic preparation and inorganic amendments

on growth, yield, and soil characteristics of cauliflower, as there is a need to examine the combined effect of jeevamrut and inorganic nutrient management.

Material and methods

Experimental site: The field investigation was conducted during two consecutive rabi seasons at the experimental farm of the Department of Vegetable Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni (30.92° N, 77.12° E; Altitude 1276m), Solan, Himachal Pradesh. The average maximum and minimum temperatures ranged from 15.71 to 29.02 °C and 1.98 to 23 °C respectively, during the first cropping season. The relative humidity ranged from 54 to 81.8% and rainfall ranged from 2.6 to 224.3 mm. During the second cropping season, average maximum and minimum temperatures ranged from 15.70 to 28.33 °C and 1.92 to 18.62 °C, respectively, while the relative humidity ranged from 57 to 77% and rainfall from 5.60 to 171.8 mm. The initial soil properties for both seasons are detailed in Table 1.

Table 1. Soil properties before planting

Particulars	Season I	Season II	Method (Reference)
Soil pH	6.73	6.75	Digital pH meter
Soil EC (dS/m)	0.41	0.43	Electrical conductivity meter
Soil organic carbon (g/kg of soil)	13.04	18.62	Rapid titration method
Available N (kg/ha)	326.91	329.14	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
Available P (kg/ha)	40.25	42.00	Olsen's method (Olsen *et al.*, 1954)
Available K (kg/ha)	215.85	222.80	Normal neutral ammonium acetate method (Merwin and Peech, 1951)

Experimental details: "Pusa Snowball K-1" was used for the research. One month old seedlings were transplanted in a randomized block design with ten treatments and three replications. The treatments consisted of T_1 (100% Recommended dose of nutrients (RDN): 250 q Farmyard manure (FYM)/hectare + 125:75:65 kg Nitrogen (N): Phosphorus (P): Potassium (K)/ hectare), T_2 [90% RDN (225 q FYM/ha + 113:68:59 kg N:P:K/ha) + 5% Jeevamrut @ 0.5 L m^{-2}], T_3 (90% RDN + 5% Jeevamrut @ 1.0 L m^{-2}), T_4 (90% RDN + 5% Jeevamrut @ 1.5 L m^{-2}), T_5 [80% RDN (200 q FYM/ha + 100:60:52 kg N:P:K/ha) + 5% Jeevamrut @ 0.5 L m^{-2}], T_6 (80% RDN + 5% Jeevamrut @ 1.0 L m^{-2}), T_7 (80% RDN + 5% Jeevamrut @ 1.5 L m^{-2}), T_8 [70% RDN (175 q FYM/ha + 88:53:46 kg N:P:K/ha) + 5% Jeevamrut @ 0.5 L m^{-2}], T_9 (70% RDN + 5% Jeevamrut @ 1.0 L m^{-2}) and T_{10} (70% RDN + 5% Jeevamrut @ 1.5 L m^{-2}). Jeevamrut was prepared following the procedure described by Devvrat (2017). Table 2 shows the nutrient content and ingredients used for its preparation. Fresh cow dung and cow urine were added to a plastic drum. Jaggery, pulse flour, and living soil were blended with water to produce a final volume of 200 L. The solution was stirred twice and filtered before use. Jeevamrut @ 5% was administered to the soil at an interval of fourteen days, starting 7 days after transplanting and continuing until 15 days before harvest. Jeevamrut has a relatively short shelf life and its preparation must coincide with key crop growth stages when nutrient demand is highest, which ensures fresh application without the need for long-term storage. Alternatively, Ghana-jeevamrut can be used whose storage life is up to 6 months. To ensure the consistency of the inputs used for preparation of jeevamrut, there is a need to control diet of cows from which dung and urine are sourced, therefore maintaining the nutrient composition of jeevamrut. The effectiveness of Jeevamrut is often attributed to the use of dung and urine from native Indian (desi) cow breeds. The recommendation against using dung and urine from non-desi cow breeds stems from the fact that these breeds are often raised primarily for milk production, and their nutrient profiles in dung and urine may be lower, as their nutrition is heavily directed towards milk quality and yield. This can lead to insufficient microbial activity, and nutrient content in the resulting Jeevamrut. For heavy feeder crops like cauliflower, integrating nutrients with fermented concoctions is effective.

Table 2. Ingredients used and nutrient content of jeevamrut

Ingredient	Quantity	Parameter	Value
Water	200 L	pH	7.07
Cow Dung	10 kg	Electrical Conductivity	3.4 dSm^{-1}
Cow Urine	10 L	Potassium	2.0 g L^{-1}
Jaggery	2 kg	Phosphorus	1.7 g L^{-1}
Pulse Flour	2 kg	Nitrogen	2.8 g L^{-1}
Fertile Soil	Handful	Carbon	7.19 g L^{-1}

Growth parameters: Observations were recorded on five randomly selected plants per plot for characters under study (days to 50% marketable curd maturity, plant height, number of leaves per plant, curd depth, curd size index, curd compactness, gross curd weight, marketable curd weight, marketable yield). Days to 50% maturity was noted from the transplanting date to curd formation. Plant height (cm) was measured with a meter scale by measuring from tip of the plant to the stem base at the ground level. The number of leaves per plant was calculated at the time of curd maturity. Curd depth (cm) was measured from the top to the base after bisecting the curd. Curd size index (cm^2) was calculated by multiplying the polar and equatorial diameters. The ratio of curd weight and depth determined curd compactness (g/ cm). Gross curd weight (kg) represents curd weight along with the leaves, whereas marketable curd weight (g) was recorded as the weight of curd without stalk and leaves. Marketable yield per plot (kg) was calculated by adding the marketable weight of the curds present in the plot. Accordingly, yield per hectare was calculated. The production efficiency (kg ha^{-1} day^{-1}) was calculated based on fruit yield (kg ha^{-1}) and the crop duration (days) (Bamboriya *et al.*, 2022).

Soil and plant parameters: Soil samples were collected from 0-15 cm depth from every plot before and after the experiment. For chemical analysis of soil organic carbon (Walkley and Black, 1934) and Nitrogen (N), Phosphorus (P) and Potassium (K), samples were air dried, crushed, passed through a 2 mm sieve, and then stored in cotton bags. For estimation of bacterial count, as recommended by Rangaswamy (1966), the serial dilution technique was used. For NPK uptake by the plant, a composite sample of two plants was randomly selected from each plot at full maturity (Tandon, 1989).

For calculating nutrient uptake in kg/ha, the N, P and K (%) content of the plant was multiplied by its biomass on a dry weight basis as indicated below.

Biomass (kg/ha) = (Weight of dry plant x 8,000)/(Area covered by the plant x 1000)

Nutrient Uptake (kg/ha) = (Biomass (kg/ha) X Nutrient content (%))/100

Monetary benefits: Monetary benefits were assessed by

calculating the cost of cultivation for every treatment. The yield (q/ha) and sale rate (₹) were multiplied to determine the gross income. The sum of the fixed cost per hectare, the risk factor, the management factor, and the cost of the treatment per hectare was used to compute the total cost of cultivation. The whole cost of cultivation was subtracted from gross income to determine gross margin. Benefit: Cost ratio was obtained by dividing gross margin by the total cost of cultivation (Sharma *et al.*, 2008).

Monetary benefits: Monetary benefits were assessed by calculating the cost of cultivation for every treatment. The yield (q/ha) and sale rate (₹) were multiplied to determine the gross income. The sum of the fixed cost per hectare, the risk factor, the management factor, and the cost of the treatment per hectare was used to compute the total cost of cultivation. The total cost of cultivation was subtracted from gross income to determine gross margin. Benefit: Cost ratio was obtained by dividing gross margin by the total cost of cultivation (Sharma *et al.*, 2008).

Monetary efficiency: Monetary efficiency, expressed as rupees per hectare per day (₹ ha^{-1} day^{-1}), was calculated from net returns (₹ ha^{-1}) and crop duration (days). This parameter provides a comprehensive measure of the financial efficiency of land utilization over a given period of time, which is the crop duration (Bamboriya *et al.*, 2022). Dominance analysis was conducted, followed by marginal analysis of the cost not dominated treatments as suggested by Mamerto (2001). Marginal rate of return (MRR) was calculated as shown below:

$$MRR = \frac{\text{Marginal Gross Margin}}{\text{Marginal Variable Cost}} \times 100$$

Statistical analysis:The OPSTAT packages and MS-Excel were used to analyze the recorded data (Sheron *et al.*, 1998). According to the model proposed by Panse and Sukhatme (2000), analysis of variance for the experiment was conducted in accordance with a randomized complete block design (RCBD). The pooled data were analyzed and treatment means were compared using Duncan's Multiple Range Test (DMRT) at the 5% level of significance.

Results

Growth parameters: Plant height ranged from 47.95 (T_8) to 49.16 (T_4), with T_4 and T_3 recording significantly superior to other treatments. T_4 (21.15) and T_3 (21.10) were significantly superior, whereas T_8 (20.17) recorded the lowest number of leaves. Minimum days to 50 per cent marketable curd maturity were recorded in T_4 (119.67) which were significantly superior among the treatments. Curd depth did not show significant variation among the treatments. Application of Jeevamrut was significant on the curd size index and curd compactness. T_4 recorded the highest curd size index (280.49 cm^2) and curd compactness (103.91 g/cm), which was significant to T_3 (279.26 cm^2) (101.79 g/cm). Minimum was recorded in T_8 with the values 195.89 cm^2 and 73.07 g/cm respectively. Gross curd weight shows significant variation among treatments ($p>0.05$), and it ranged from 2.06 kg to 1.41 kg under treatments T_4 and T_8, respectively. Treatment T_4 and T_3 were statistically similar. Table 3 showed the highest marketable curd weight was recorded in T_4 (881.16 g), which was significantly similar to T_3 (861.91 g) and T_8 (604.58 g), which recorded the lowest marketable curd weight. Value of marketable yield per plot ranged from 10.65 kg (T_8) to 15.45 kg (T_4). Treatments T_4 and T_3 had significantly higher marketable yield (Fig. 1). However, there is no significant difference among treatments for marketable yield per hectare (q/ha) (Fig. 2). Production efficiency also varied significantly as identified in Table 3, with T_4 (188.82 kg ha^{-1} day^{-1}) achieving the highest efficiency as compared to T_8 (130.31 kg ha^{-1} day^{-1}) and T_9 (144.31 kg ha^{-1} day^{-1}).

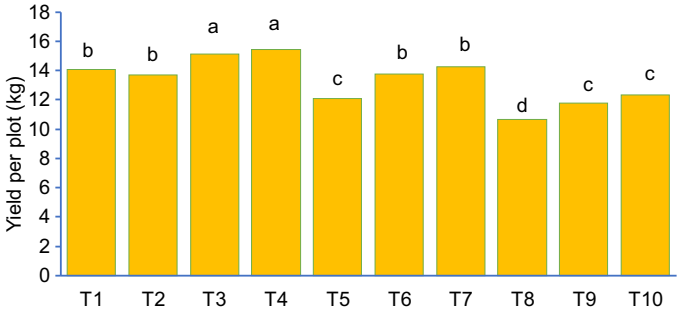


Fig. 1. Comparative analysis of treatments on yield per plot of cauliflower. Using Duncan's multiple range test, the values with similar letters do not differ significantly at 5% level.

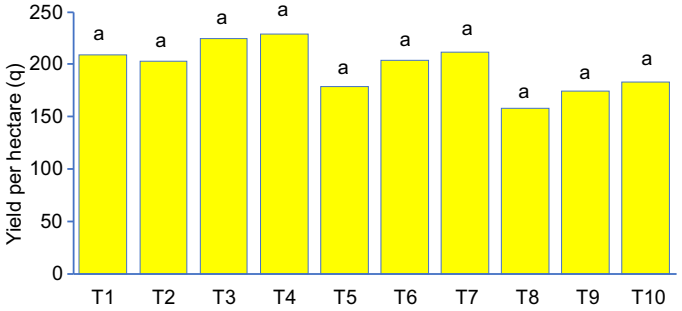


Fig. 2. Comparative analysis of treatments on yield per hectare of cauliflower. Using Duncan's multiple range test, the values with similar letter do not differ significantly at 5% level.

Table 3. Effect of jeevamrut and chemical fertilizers on growth and yield characteristics of cauliflower

Treatment	Plant height (cm)	Number of leaves/ plant	Days to 50 % market maturity	Curd depth (cm)	Curd size index (cm^2)	Curd compactness (g/cm)	Gross curd weight (kg)	Marketable curd weight (g)	Production efficiency (kg ha^{-1} day^{-1})
T_1	48.73^{c}	20.93^{ab}	121.23^{abcd}	8.40^{a}	259.16^{b}	95.15^{b}	1.87^{ab}	799.88^{b}	172.43^{ab}
T_2	48.56^{cd}	20.79^{ab}	121.00^{bcd}	8.38^{a}	253.45^{b}	93.46^{b}	1.68^{bcd}	782.23^{b}	167.51^{bcd}
T_3	49.08^{ab}	21.10^{a}	120.33^{cd}	8.47^{a}	279.26^{a}	101.79^{a}	2.01^{a}	861.91^{a}	185.51^{ab}
T_4	49.16^{a}	21.15^{a}	119.67^{d}	8.48^{a}	280.49^{a}	103.91^{a}	2.06^{a}	881.16^{a}	188.82^{a}
T_5	48.24^{de}	20.52^{ab}	122.33^{ab}	8.31^{a}	225.06^{c}	83.75^{c}	1.54^{cd}	694.64^{c}	147.84^{de}
T_6	48.69^{c}	20.88^{ab}	122.00^{abc}	8.40^{a}	253.18^{b}	92.99^{b}	1.82^{abc}	781.43^{b}	168.58^{abc}
T_7	48.78^{bc}	20.95^{ab}	121.33^{abcd}	8.41^{a}	262.51^{b}	96.28^{b}	1.85^{abc}	810.20^{b}	174.58^{ab}
T_8	47.95^{e}	20.17^{b}	123.00^{a}	8.27^{a}	195.89^{d}	73.07^{d}	1.41^{d}	604.58^{d}	130.37^{e}
T_9	48.25^{de}	20.54^{ab}	122.67^{ab}	8.32^{a}	216.67^{c}	80.32^{c}	1.59^{bcd}	680.74^{c}	144.31^{e}
T_{10}	48.32^{de}	20.61^{ab}	122.33^{ab}	8.34^{a}	227.11^{c}	84.07^{c}	1.63^{bcd}	700.97^{c}	151.01^{cde}

Figures with same letter in column do not differ significantly.

Soil and plant parameters: The treatments had no significant effect on soil pH and EC as referred in Table 4. T_4 (22.40 g/kg of soil) and T_3 (21.83 g/kg of soil) recorded significantly higher soil organic carbon compared to others, whereas the minimum was recorded in T_8 (15.27 g/kg of soil). Bacterial count was significantly higher in T_4 (230.80 × 106 cfu/g) and T_3 (223.87 × 106 cfu/g) as compared to T_1, which had the minimum bacterial count (168.05 × 106 cfu/g). The available nitrogen ranged from 240.11 kg/ha (T_8) to 377.23 kg/ha (T_3). T_3 and T_4 were statistically similar. For available phosphorus T_4 (46.93 kg/ha) and T_3 (45.84 kg/ha) were significantly superior, whereas T_8 (32.12 kg/ha) had the lowest phosphorus availability. The available potassium varied from 136.234 (T_8) to 256.01 (T_3), with T_3 and T_4 showing statistical similarity. The total NPK uptake by the plants increased by jeevamrut application. T_4 showed the highest uptake of nitrogen (67.53 kg/ha), phosphorus (11.67 kg/ha) and potassium (49.18 kg/ha). Followed closely by T_3. The lowest uptake across all nutrients was recorded in T_8, as described in Table 5.

Monetary benefits: The highest benefit cost ratio was in T_3 (2.08) which was statistically similar to T_4, while T_8 had the lowest (1.51) (Fig. 5). Table 6 depicts that ₹ 1,570 to 2,538 per day net benefit was generated from one hectare area. T_4 (2538.52 ₹ ha^{-1} day^{-1}), being most profitable, was statistically at par with T_3 (2503.97 ₹ ha^{-1} day^{-1}).

Table 4. Effect of jeevamrut and chemical fertilizers on pH, EC, soil organic carbon and bacterial count of soil

Treatment	pH	EC (dsm^{-1})	SOC (g/kg)	Bacterial count (× 10^6 cfu/g of soil)
T_1	6.67^{a}	0.37^{a}	17.81^{c}	168.05^{f}
T_2	6.65^{a}	0.39^{a}	19.97^{b}	205.34^{cde}
T_3	6.71^{a}	0.36^{a}	21.83^{a}	223.87^{ab}
T_4	6.68^{a}	0.34^{a}	22.40^{a}	230.80^{a}
T_5	6.71^{a}	0.39^{a}	17.89^{c}	198.78^{e}
T_6	6.77^{a}	0.32^{a}	19.72^{b}	202.72^{de}
T_7	6.55^{a}	0.35^{a}	20.48^{b}	211.50^{cd}
T_8	6.71^{a}	0.33^{a}	15.27^{d}	202.02^{de}
T_9	6.70^{a}	0.35^{a}	16.87^{c}	211.13^{cde}
T_{10}	6.66^{a}	0.33^{a}	17.83^{c}	217.02^{bc}

Figures with same letter in column do not differ significantly

Table 5. Effect of jeevamrut and chemical fertilizers on available N, P and K and uptake by cauliflower

Treatment	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	N uptake (kg/ha)	P uptake (kg/ha)	K uptake (kg/ha)
T_1	337.37^{b}	42.51^{b}	220.45^{b}	61.55^{b}	10.64^{b}	41.72^{c}
T_2	329.60^{b}	41.74^{b}	213.47^{b}	59.79^{b}	10.33^{b}	43.57^{bc}
T_3	377.23^{a}	45.84^{a}	256.01^{a}	66.22^{a}	11.45^{a}	48.26^{a}
T_4	367.30^{a}	46.93^{a}	247.49^{a}	67.53^{a}	11.67^{a}	49.21^{a}
T_5	286.03^{c}	37.19^{c}	175.89^{c}	52.77^{c}	9.12^{c}	38.46^{d}
T_6	327.51^{b}	41.51^{b}	212.59^{b}	60.17^{b}	10.40^{b}	43.83^{bc}
T_7	341.72^{b}	43.07^{b}	225.10^{b}	62.32^{b}	10.77^{b}	45.41^{b}
T_8	240.11^{d}	32.12^{d}	136.23^{d}	46.54^{d}	8.04^{d}	33.91^{e}
T_9	288.07^{c}	35.51^{c}	163.89^{c}	51.51^{c}	8.90^{c}	37.54^{d}
T_{10}	271.47^{c}	37.27^{c}	177.98^{c}	53.90^{c}	9.32^{c}	39.28^{d}

Figures with same letter in column do not differ significantly

Monetary benefits: The highest benefit cost ratio was in T_3 (2.08) which was statistically similar to T_4, while T_8 had the lowest (1.51) (Fig. 5). Marginal rate of return analysis based on gross margin and total variable cost, indicated that treatments T3, T4, T5, T6, T7, T8, T9 and T10 were cost not dominated. Table 7 revealed that maximum marginal rate of return was obtained from T10 (5255.94 %) followed by T6 (905.94%). It indicated that 70% RDN + 5% jeevamrut @ 1.5 L/m2 would maximize the rate of return to capital.Table 6 depicts that ₹ 1,570 to 2,538 per day net benefit was generated from one hectare area. T_4 (2538.52 ₹ ha^{-1} day^{-1}), being most profitable, was statistically at par with T_3 (2503.97 ₹ ha^{-1} day^{-1}).

Table 6. Effect of jeevamrut and chemical fertilizers on economics of cauliflower

Treatment	Yield (q/ha)	Cost of Cultivation (₹)	Gross Income (₹)	Gross margin (₹)	B:C Ratio	Monetary efficiency (₹ ha^{-1} day^{-1})
T_1	208.64^{a}	141965	417280	275315	1.94^{ab}	2275.33^{ab}
T_2	202.69^{a}	141589	405380	263791	1.86^{bc}	2180.09^{b}
T_3	224.47^{a}	145959	448940	302981	2.08^{a}	2503.97^{a}
T_4	228.47^{a}	149779	456940	307161	2.05^{a}	2538.52^{a}
T_5	178.89^{a}	133542	357780	224238	1.68^{de}	1853.21^{cd}
T_6	203.98^{a}	137912	407960	270048	1.96^{ab}	2231.80^{b}
T_7	211.24^{a}	141732	422480	280748	1.98^{ab}	2320.23^{ab}
T_8	157.75^{a}	125496	315500	190004	1.51^{e}	1570.28^{d}
T_9	174.62^{a}	129866	349240	219374	1.69^{cde}	1813.01^{cd}
T_{10}	182.72^{a}	133686	365440	231754	1.73^{cd}	1915.32^{c}

Table 7. Effect of jeevamrut and chemical fertilizers on marginal rate of return analysis of cauliflower

Treatment	Total variable cost (₹/ha)	Δ Marginal variable cost (₹/ha)	Gross margin (₹/ha)	Δ Marginal gross margin (₹/ha)	Marginal rate of return (%)
T_8	63995	-	190004	-	-
T_9	68365	4370	219374	29370	672.08
T_5	72043	3678	224238	4864	132.25
T_{10}	72186	143	231754	7516	5255.94
T_6	76413	4227	270048	38294	905.94
T_7	80232	3819	280748	10700	280.18
T_3	84459	4227	302981	22233	525.98
T_4	88279	3820	307161	4180	109.42

Marginal rate of return analysis based on gross margin and total variable cost, indicated that treatments T_3, T_4, T_5, T_6, T_7, T_8, T_9 and T_{10} were cost not dominated. Table 7 revealed that maximum marginal rate of return was obtained from T_{10} (5255.94%) followed by T_6 (905.94%). It indicated that 70% RDN + 5% Jeevamrut @ 1.5 L m^{-2} would maximize the rate of return to capital.

Discussion

Growth parameters: In addition to having enough food reserves, the conjoint application of the recommended dose of fertilizers and jeevamrut has increased vegetative growth, likely due to a larger population of microorganisms. These microorganisms' breakdown the organic materials and release resources, leading to increased production and growth. Organic compounds also function as chelates, aiding iron and other micronutrient absorption, while the addition of FYM gradually releases nutrients through the mineralization process. These results are in agreement to Kumbar and Devakumar (2016), Hameedi *et al.* (2018), and Uttam *et al.* (2021). Application of Jeevamrut + Hoagland nutrient solution in lettuce improved all the growth parameters (Spehia *et al.*, 2018) which may be because of greater nutrient availability at initial stages through synthetic fertilizers, in addition to jeevamrut's nutritional value. According to Rathore *et al.* (2023) growth of brinjal was increased due to sufficient availability of nutrients, which improved translocation

of photoassimilates. The slow and steady release of nutrients in whole crop cycle helped in improved growth and yield in tomato (Gopal and Lingaraju, 2022). The presence of certain microbial substances present in jeevamrut might have showed resistance against pest and diseases. The occurrence of advantageous microorganisms in these fermented organic liquid preparations could primarily stem from their components, which include cow dung, cow urine, legume powder, and jaggery. These constituents are rich in both macro and essential micronutrients, numerous vitamins, crucial amino acids, growth-enhancing compounds like indole acetic acid (IAA) and gibberlic acid (GA), as well as beneficial microorganisms (Sharma *et al.*, 2021). According to Spehia *et al.* (2022), all the growth parameters improved in Indian palak (*Beta vulgaris* L. var. *bengalensis* Roxb.) with the application of Nutrient Film Technique + 5 % jeevamrut because jeevamrut was applied through foliar spray and as a result it was directly available to plants.

Soil and plant parameters: Jeevamrut treatment increased organic carbon content, which improved soil microbial activity and chemical characteristics. Its abundant microbial diversity and metabolites promote beneficial interactions amongst soil microorganisms. Saharan *et al.* (2023) found that farmer's fields had lower levels of organic carbon and nutrients compared to ZBNF. Cauliflower soils treated with vermicompost and Jeevamrut at 1.5 L/4.32 m² showed higher NPK content (Sharma *et al.*, 2022). FYM and Jeevamrut enhanced microbial activity, promoting nitrogen mineralization, phosphate solubilization, and potassium release via humic acids and rhizospheric activities. Rathore *et al.* (2022) found that increased enzymatic activity, including dehydrogenase and phosphatase, improved nutritional availability in eggplant.

In addition to nutrients, growth regulators like auxins and GA are encouraged by jeevamrut, helping to produce more biomass. Kumbar and Devakumar (2016) reported that jeevamrut's microbial load in trial conducted on French bean, multiplies in soil and boost microbial activity. According to Shraddha *et al.* (2023) 90% RDN (112.5 N: 67.5 P: 46.8 K kg/ha) + 5% jeevamrut (1.5 L m^{-2}) + 5% jeevamrut foliar spray obtained the greatest organic carbon (20.93 g/kg), available N (375.13 kg/ha), P (48.46 kg/ha), K (260.53 kg/ha) in the soil as well as more uptake of N (60.58 kg/ha), P (7.25 kg/ha), and K (37.88 g/ha) by the plants.

Economics: According to Vashishat *et al.* (2023) there was a significant increase in net income of farmers and a decrease in cost of production in natural farming practices. The cost of cultivation per hectare in natural farming was decreased by 23% in Tomato-capsicum-frenchbean, 30% in Tomato-frenchbean, 38% in Capsicum-frenchbean, 14% in Pea-cauliflower and 12% in Pea-cabbage. Also, increase in income was 24% in Tomato capsicum-frenchbean, 35% in Tomato-frenchbean, 49% in Capsicum-frenchbean, 22% in Pea-cauliflower and 36% in Pea-cabbage farming pattern. Highest benefit cost ratio was reported in no organic manure + jeevamrut (Drenching @ 5 % + Foliar spray @ 3 %) treatment in capsicum (Hameedi *et al.*, 2022) which could be attributed to the cut down cost of production as these are prepared from the in-farm products like cow urine, cow dung, jaggery and gram flour which further incurred to better yield, sustainable production of the crop as well as higher net returns to the farmers. According to Shraddha *et al.* (2023) 90% RDN (112.5 N: 67.5 P: 46.8 K kg/ha) + 5% jeevamrut (1.5 L/m^2) + 5% jeevamrut foliar spray obtained the greatest value for gross margin (₹ 245840) and cost-benefit ratio (1.93).

From the results, it can be concluded that cauliflower can be produced through application of 90% RDN + 5% Jeevamrut @1.5 L m^{-2}, which gave best results in terms of growth, yield and yield contributing characters. On the other hand, 90% RDN + 5% Jeevamrut @ 1.0 L m^{-2} produced the best results for N and K content in soil and B:C ratio. In this study it was observed that application of jeevamrut improves he soil biology as it enhances the soil microbial and chemical properties. So, by adding these fermented organic concoctions to agriculture may cut down the synthetic fertilizers usage and improve the economics furthermore leading to sustainable crop production. In future, the long-term effects of jeevamrut on soil health and nutrient dynamics across different crop cycles and agro-climatic regions must be studied. Additionally, optimizing the application rates of jeevamrut in cauliflower and other important vegetables could enhance its economic viability and environmental sustainability, promoting its wider adoption in sustainable agriculture.

Data availability statement: The data presented in the study are available on request from the corresponding author.

Authors' contribution: Sushain Sharma conducted the field experiment. Shraddha drafted the manuscript. Yog Raj Shukla and Kuldeep Thakur conceptualized the research. Rohit Kumar Vashishat assisted in manuscript preparation. Jagjeet Chand Sharma contributed to the critical review and refinement of the final manuscript. All authors have read and approved the final version of the manuscript.

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