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Differential Responses to Integrated Nutrient Management of Cabbage–Capsicum–Radish Cropping Sequence with Fertilizers and Plant-Growth-Promoting Rhizobacteria

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Abstract: The present investigation was carried out to study the differential responses to assimilated nutrient management in the cabbage–capsicum–radish cropping system to develop an integrated plant nutrient supply. The experimental trial was laid out in a randomized complete block design (RCBD) with three replicates and included assimilations of 15 various combinations: T_1—recommended dose of fertilizers (RDFs) + farmyard manure (FYM) (Control); T_2—nitrogen and phosphorus (NP) + vermicompost (VC) (75% + 2.5 t/ha); T_3—NP + VC (50% + 2.5 t/ha); T_4—NP + enriched compost (EC) (75% + 2.5 t/ha); T_5—NP + EC (50% + 2.5 t/ha); T_6—NP + plant-growth-promoting rhizobacteria (PGPR) (75% + 5 kg/ha); T_7—NP + PGPR (50% + 5 kg/ha); T_8—NP + VC + PGPR (75% + 2.5 t/ha + 5 kg/ha); T_9—NP + VC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{10}—NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{11}—NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{12}—NP + VC and EC (75% + 2.5 t/ha and 2.5 t/ha); T_{13}—NP + VC and EC (50% + 2.5 t/ha and 2.5 t/ha); T_{14}—NP + VC and EC + PGPR (75% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha); T_{15}—NP + VC and EC + PGPR (50% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha) for two consecutive years. Seedlings of the cabbage cultivar were transplanted with a spacing of 45 × 30 cm, whereas the capsicum seedlings were transplanted with a spacing of 60 × 45 cm. The radish cultivar was sown directly in the field with a spacing of 30 × 7.5 cm. The yield and growth attributes of all three crops were notably impacted by the INM modules. The utilization of a combination of 75% of the recommended quantity of NP + VC and EC, along with PGPR, at a rate of 2.5 t/ha, during cabbage cultivation, led to a noteworthy rise in plant height, equatorial diameter, gross head weight, net head weight, and ultimately, the maximum head yield, as per the statistical analysis. In the case of capsicum, the treatment (T_{14}) module demonstrated superior performance in terms of the major yielding components, namely, fruit size, fruit weight, and number of fruits per plant, resulting in the highest yield compared to the other modules, including RDFs. The cabbage exhibited high protein content and inorganic modules in terms of quality traits, whereas ascorbic acid and total soluble solids (TSSs) levels were high due to strong organic support across all three crops. Thus, it can be inferred that the integrated combination of 75% NP, VC, and EC at 2.5 t/ha, and PGPR, along with the basic application of the full recommended potash and farmyard manure (FYM), led to a reduction of 25% in fertilizers (NP), improved growth and yield, and higher annual net returns. Thus, this incorporation can be suggested as an economically efficient strategy for consistently attaining increased productivity with enhanced excellence.

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1. Introduction

Integrated nutrient management (INM) refers to the application of all possible sources of plant nutrients in an integrated manner. This helps in improving the nutrition-application system by using reduced fertilizer doses and incorporating bioinoculants, which will lessen fertilizer losses and harmonize with the demand for crop nutrients [1]. Our country's (India's) fruit and vegetable supply has increased dramatically over the past several decades, moving it into second place among all other nations with a yield of 191.76 MT from an area of 10,353 thousand hectares [2]. By the year 2030, the vegetable demand of our country will be 350 million metric tons, and for the fulfillment of a balanced and nutritive diet, we will require 400 g of vegetables per person per day [3]. In Himachal Pradesh, with the coming of the era of crop diversification, vegetable cultivation is gaining significant importance due to favorable agro-climatic conditions for the growth and development of quality off-season vegetable crops, viz., French beans, cauliflower, tomatoes, cabbage, peas, capsicum, etc. A cropping system like cabbage–capsicum—radish is one of the cropping sequences used for mid-hill areas that can be favorable for the year-round production of crops with enhanced soil conditions [4].

With an improvement in the quality and increased production of vegetable crops, soil health is an essential consideration. The complex structure of biogeochemical cycles has frequently been harmed by the use of chemical sources to increase agricultural yield and soil fertility [5]. For instance, the use of inorganic fertilizers has resulted in the leaching and run-off of fertilizers, particularly N and P, which has caused environmental deterioration. To achieve maximum crop output and optimal nutrient use efficiency, a balance must be struck [6]. Among the many signs of soil deterioration, the over-mining of minerals is seen as a serious problem, especially in cropping systems based on vegetables that require extensive irrigation [7]. This is taking place because the amount of nutrients being removed from the soil by crops has far outweighed the amount being replaced by fertilizers [8]. As a result, farmers nowadays are more motivated to employ ecologically friendly farming methods.

Mineral fertilizers, organic manures, and the inoculation of plant-growth-promoting rhizobacteria are viable ways to lessen the negative environmental effects of the excessive use of chemical fertilizers. In turn, this will support maintaining ecological viability in terms of soil fertility and agricultural yield, as well as fulfilling the nutritional requirements of the crops. An integrated strategy has assisted in improving the efficiency of fertilizer use in intensive cropping systems [9].

The inoculation of microorganisms has demonstrated considerable potential and has emerged as a significant constituent of integrated plant nutrient supply (IPNS). Renewable-energy-based inputs are not only cost-effective but also environmentally friendly. Moreover, it has been reported that they enhance soil properties and promote long-term soil health [3–5]. Adopting an integrated approach that includes the use of natural manures, mineral-based fertilizers, and inoculation with PGPR is one potential strategy for reducing the negative environmental effects linked to the inefficient utilization of chemical fertilizers. Consequently, this will aid in fulfilling the crops' nutrient needs while also upholding sustainability regarding productivity and soil fertility. Moreover, the mechanisms attributed to plant-growth-promoting rhizobacteria (PGPR) include the regulation of hormonal and nutritional equilibrium, the elicitation of plant resistance against pathogenic microorganisms, and the facilitation of nutrient solubilization for enhanced plant uptake [6].

The implementation of an integrated approach has resulted in an improvement in fertilizer use efficiency within intensive cropping systems. The present investigation has been carried out to evaluate the effects of the combined use of biological manures, inorganic fertilizers, and PGPR on growth, productivity, and quality in the context of a cropping sequence involving cabbage, capsicum, and radish, while taking into account the aforementioned factors. Therefore, the objective of the current study is to develop an assimilated crop nutrition through the sustainable usage of organic and inorganic nutrient resources, as well as rhizobacteria that promote plant growth, for cropping systems based on cabbage, capsicum, and radish.

2. Materials and Methodology

2.1. Experimental Location

In the Dr. Y.S. Parmar University of Horticulture and Forestry, Solan (HP), the experiment was conducted for two years to develop an INPS module for higher productivity and improved soil health under the cabbage–capsicum–radish cropping sequence. According to agro-climatology, the area lies in Himachal Pradesh′s mid-hill zone and has a sub-temperate to sub-tropical climate with modest rainfall (1000–1300 mm). The Experimental Farm is situated at 35°51′ N latitude and 77°11′ E longitude at an elevation of 1270 m (a m s l) at Nauni, on Rajgarh Road, about 15 km south-east of Solan (HP). The initial status of the soil was recorded for soil pH, EC, organic carbon, nitrogen, phosphorus, and potassium as 6.95, 0.56 dS/m, 1.18%, 323.76, 43.63, and 394.58 (N, P, K in kg/ha), respectively.

2.2. Treatment Details

The experiment was set up in a randomized complete block design with three replicates containing each of the following 15 assimilated treatment (T) combinations: T_1—recommended dose of fertilizers (RDFs) + farmyard manure (FYM) (Control); T_2—nitrogen and phosphorus (NP) + vermicompost (VC) (75% + 2.5 t/ha); T_3—NP + VC (50% + 2.5 t/ha); T_4—NP + enriched compost (EC) (75% + 2.5 t/ha); T_5—NP + EC (50% + 2.5 t/ha); T_6—NP + plant-growth-promoting rhizobacteria (PGPR) (75% + 5 kg/ha); T_7—NP + PGPR (50% + 5 kg/ha); T_8—NP + VC + PGPR (75% + 2.5 t/ha + 5 kg/ha); T_9—NP + VC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{10}—NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{11}—NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{12}—NP + VC and EC (75% + 2.5 t/ha and 2.5 t/ha); T_{13}—NP + VC and EC (50% + 2.5 t/ha and 2.5 t/ha); T_{14}—NP + VC and EC + PGPR (75% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha); T_{15}—50% NP + VC and EC @ 2.5 t/ha + PGPR (50% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha) for two consecutive years (Figure 1). The NPK was administered according to the established treatment, which included urea (containing 46% nitrogen), single super phosphate (containing 16% phosphorus), and muriate of potash (containing 60% potassium). The present study determined the most effective recommended quantities of fertilizers, specifically the recommended doses of fertilizers (RDFs), for various vegetable crops grown in an annual sequence. The recommended doses for cabbage were 125:110:50 kg NPK along with 20 t/ha FYM, for capsicum they were 100:75:55 kg NPK along with 20 t/ha FYM, and for radish they were 100:48:36 kg NPK along with 10 t/ha FYM. In the present study, all treatment plots were provided with a basal dressing of nitrogen and phosphorus, along with a full dose of potash, across the three crops in the sequence. In the case of cabbage and capsicum, N was administered in three divided doses. The initial dose, equivalent to one-third of the total N required, was applied as basal dressing. The remaining two doses were administered at monthly intervals thereafter. A basal dose of half N was administered during the sowing of radish, with the remaining half being applied three weeks later during the implementation of hoeing and earthing-up procedures. All treatment plots got the same amount of farmyard manure (FYM), as well as equal amounts of vermicompost (VC), enriched compost (EC), and a mix of VC and EC. The incorporation of these manures into the individual plots was carried out manually during the preparation stage.

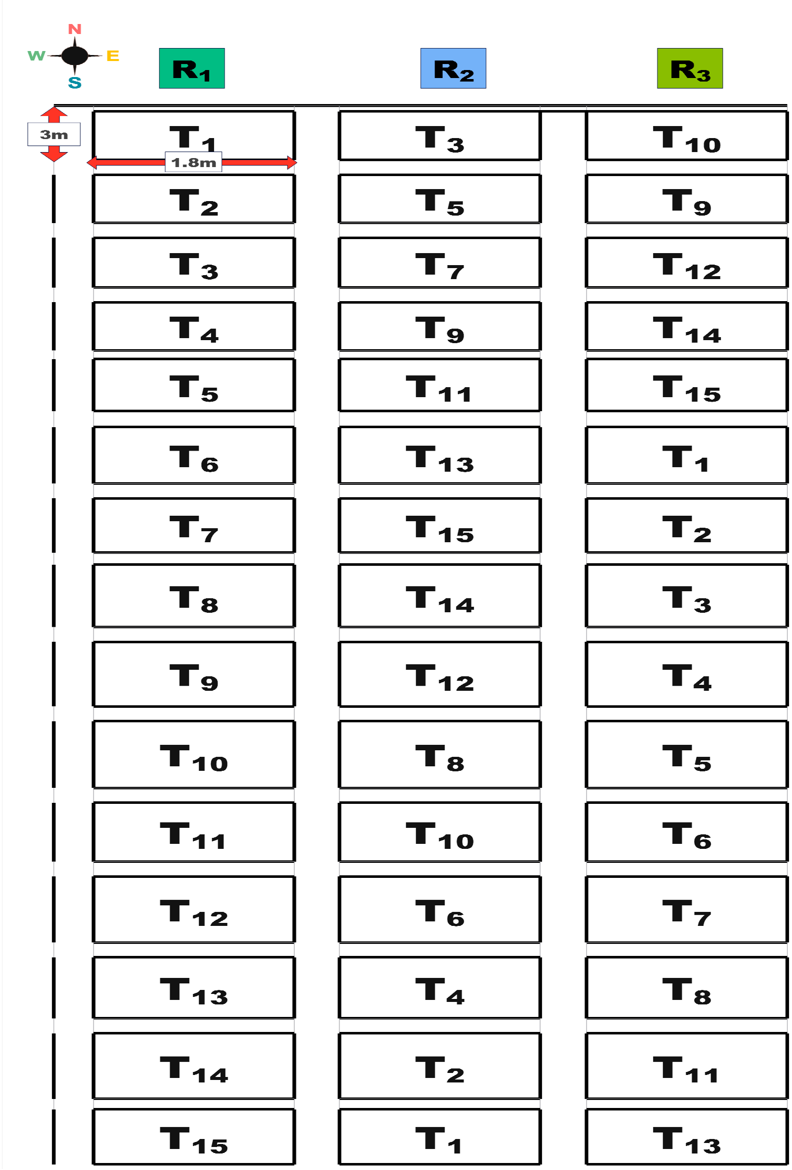

Figure 1. Layout of an experiment (R—replication; T—treatment; T_1—RDFs + FYM (Control); T_2—NP + VC (75% + 2.5 t/ha); T_3—NP + VC (50% + 2.5 t/ha); T_4—NP + EC (75% + 2.5 t/ha); T_5—NP + EC (50% + 2.5 t/ha); T_6—NP + PGPR (75% + 5 kg/ha); T_7—NP + 5 kg/ha); T_8—NP + VC + PGPR (75% + 2.5 t/ha + 5 kg/ha); T_9—NP + VC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{10}—NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{11}—NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha); T_{12}—NP + VC and EC (75% + 2.5 t/ha and 2.5 t/ha); T_{13}—NP + VC and EC (50% + 2.5 t/ha and 2.5 t/ha); T_{14}—NP + VC and EC + PGPR (75% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha); T_{15}—NP + VC and EC + PGPR (50% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha).

2.3. Planting Material

The Department of Basic Sciences, UHF, Nauni, discovered the isolate of *Bacillus licheniformis* strain CKA1 from the apple tree (host plant), a type of plant-growth-promoting rhizobacteria, and the strain was utilized as a singular entity possessing multifunctional traits that promote plant growth. The seeds or seedlings were immersed in liquid culture of *Bacillus* sp. formulation (cell density approximately 10^8 cfu/mL) or distilled water, according to treatments, for 3 to 4 h in a glass tumbler before being sown or transplanted. Cabbage and capsicum seeds, both inoculated and uninoculated, were sown with extra care in $1.0 \times 1.0 \times 0.15$ m seed beds in both years. The cabbage cultivar, Pusa Mukta, was planted with a spacing of 45×30 cm, while the capsicum cultivar, Solan Bharpur, was planted with a spacing of 60 × 45 cm. The Chinese Pink radish seeds were sowed directly with a final spacing of 30 × 7.5 cm. The cropping sequence in terms of sowing and harvest is given in Table 1.

Table 1. Crop details along with sowing time.

Parameters \ Crop	Cabbage	Capsicum	Radish
Design	(RCBD)	(RCBD)	(RCBD)
Replication (s)	3	3	3
Treatments	15	15	15
Plot size	3 × 1.8 m^2	3 × 1.8 m^2	3 × 1.8 m^2
Variety	Pusa Mukta	Solan Bharpur	Chinese Pink
Date of seed sowing (nursery/direct sowing)	8 September	7 March	22 August
Date of transplanting	12 October	17 April	-

2.4. Cultural Practices

The enhanced compost was produced by decomposing different vegetative agricultural wastes. On the surface of the trench, a 30 cm-thick layer of farm waste was put over a thin coating of the slurry made from cow manure. The cow dung slurry was reapplied to the different layers of waste. Thereafter, enrichment with inorganic fertilizers, i.e., phosphorus and nitrogen, was carried out according to the practice of SSP doses at the rate of 400 g and urea at the rate of 200 g per layer. The pit was filled with four layers of agricultural waste, which were then stacked to a height of approximately 50 cm above the ground and covered with a thin layer of dirt. The compost was curved twice every two months, for better aeration in the pit and to ready it for use after 6 months. The composted manure, based on testing, contained: enriched compost—N: 0.5%, P: 0.25%, K:0.5%; VC—N: 1.0% P: 1.5% K: 1.2%.

2.5. Growth Parameters

Data pertaining to different observations, namely, growth and yield parameters, as well as quality traits, were collected from all three crops in the sequence, namely cabbage, capsicum, and radish. The plants were selected randomly from each experimental plot, and their mean values were calculated for statistical analysis. The exclusion of plants located in the outer rows was implemented to mitigate the potential influence of the border effect.

Using a measuring scale, the harvest-stage height of 10 cabbage plants, randomly selected from each plot/treatment or replication, was determined from the soil level to the surface of the head. The spread of ten identical plants was measured as the distance between their two outermost leaves. At the time of the last harvest of capsicum, the plant height (cm) of six randomly selected plants was determined by measurement from the bottom to the top of the main branch. In the same six plants, the number of laterals arising from the main stem was determined. The length and width of the root in radishes at harvest, using the length of 10 marketable roots randomly selected from each plot or treatment, was measured in centimeters with the help of a digital vernier caliper.

2.6. Yielding Attributes

The polar diameter of cabbage, using the same method of selecting 10 marketable heads, was measured in centimeters with the help of a digital vernier caliper. After recording the polar diameter, the equatorial diameter in centimeters was also measured with the help of a digital vernier caliper. Based on the yield obtained per plot in kg, the yield per hectare in quintals was calculated. For capsicum, the fruit length (cm) at the third harvest from random plots was measured using a digital vernier caliper, excluding the pedicel length. The fruit breadth (cm) was also measured using a digital vernier caliper. The total quantity of crops harvested from the same six random plants during multiple harvests was determined. The production per ha was calculated in quintals based on the harvest in kilograms obtained from each plot. The average root weight of the radish was determined by weighing 10 marketable roots randomly selected from each plot or treatment and recording the results in grams. The yield per hectare was calculated in quintals based on the yield acquired from each plot in kilograms (by combining the weight of all crops harvested across all pickings in a given plot or treatment).

2.7. Physicochemical Attributes

According to the prescribed procedure of the Association of Official Agricultural Chemists, the ascorbic acid content of a cabbage head was determined using 2,6-dichlorophenol indophenol dye (mg/100 g). The protein content of the cabbage head was determined by multiplying the nitrogen content of the head by 6.25. Using a refractometer, the total soluble solids of five random third-harvest fruits were determined for each treatment and expressed in degrees Brix.

2.8. Cost Economics

To determine the cost of cultivation, all expenditures on cultural activities and the input expenses applied to each experimental plant were taken into account. Net returns per hectare and the economics of various treatments were analyzed. The benefit-to-cost (B:C) ratio was also calculated to determine the commercial viability of the investigated treatments. The economic details of all the combinations were calculated.

$$\text{Gross return from crops (Rs/ha)} = \text{Returns from fruit yield}$$

$$\text{Net returns} = \text{Gross return} - \text{Total cost of cultivation}$$

2.9. Statistical Analysis

Under the experimental design, MS Excel, Wasp-ICAR, and SPSS-21 software (SPSS, Chicago, IL, USA) were used to analyze the collected data. The analysis of variance was statistically assessed using the RBD analysis process.

3. Results

3.1. Differential Effects of Assimilated Nutrient Management on the Growth Attributes

The combined use of vermicompost and enriched compost, inorganic fertilizers, and plant-growth-promoting rhizobacteria helped all three crops in the sequence significantly. In Table 2, with two years of data collected for cabbage, the tallest individuals after the various courses of action are shown. However, the bio-inoculated modules, which recorded taller plants with treatments T14, T6, and T15 (in decreasing order), and which were statistically equivalent to the RPF, significantly minimized (75 or 50 percent) the dose of recommended fertilizers (NP), with or without VC and EC. Through RPF, the significant maximum plant spread of cabbage was also reported. RPF produced the tallest plants and the most branches in capsicum as well. With 75 percent NP + VC and EC (both 2.5 t/ha) + PGPR (5 kg per ha), the mean root length and root diameter in radishes were found to be at their highest levels. Overall, the application of modules with 75 percent NP and organic mixtures of VC and EC (both 2.5 t/ha) along with PGPR (5 kg/ha) promoted the growth characteristics.

Table 2. Differential effects of assimilated nutrient management on growth attributes in a cabbage–capsicum–radish-based cropping sequence.

Code	Treatment	Cabbage		Capsicum		Radish	
		Plant Height (cm)	Plant Spread (cm)	Plant Height (cm)	Number of Branches	Root Length (cm)	Root Diameter (cm)
T_1	RDFs + FYM (Control)	26.22 ± 0.22 a	62.38 ± 1.05 a	60.75 ± 0.47 a	4.07 ± 0.16 a	9.59 ± 0.47 d–f	3.23 ± 0.03 c–g
T_2	NP + VC (75% + 2.5 t/ha)	25.14 ± 0.20 b–d	57.28 ± 0.48 b	56.60 ± 0.44 d	3.67 ± 0.12 bc	10.63 ± 0.25 a–d	3.15 ± 0.04 g
T_3	NP + VC (50% + 2.5 t/ha)	23.71 ± 0.48 fg	51.66 ± 0.39 e–g	52.54 ± 1.14 f	3.00 ± 0.03 gh	9.29 ± 0.20 f	3.17 ± 0.2 fg
T_4	NP + EC (75% + 2.5 t/ha)	24.45 ± 0.22 d–f	54.66 ± 0.93 cd	51.75 ± 0.89 f	3.30 ± 0.10 de	10.02 ± 0.43 c–f	3.20 ± 0.04 d–g
T_5	NP + EC (50% + 2.5 t/ha)	23.63 ± 0.40 g	51.47 ± 0.75 fg	49.69 ± 1.21 g	3.17 ± 0.07 e–g	9.69 ± 0.38 d–f	3.05 ± 0.01 h
T_6	NP + PGPR (75% + 5 kg/ha)	25.67 ± 0.72 ab	54.63 ± 1.21 cd	57.91 ± 0.57 bc	3.53 ± 0.12 bc	9.78 ± 0.42 c–f	3.24 ± 0.03 b–g
T_7	NP + PGPR (50% + 5 kg/ha)	24.20 ± 0.02 e–g	51.93 ± 0.73 e–g	54.45 ± 1.05 e	3.53 ± 0.08 bc	9.40 ± 0.72 ef	3.17 ± 0.03 e–g
T_8	NP + VC + PGPR (75% + 2.5 t/ha + 5 kg/ha)	24.83 ± 0.22 c–e	54.79 ± 0.56 cd	56.73 ± 0.71 cd	3.17 ± 0.12 e–g	10.90 ± 0.39 a–c	3.22 ± 0.04 c–g
T_9	NP + VC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	23.73 ± 0.11 fg	50.31 ± 0.43 g	51.88 ± 0.43 f	2.93 ± 0.02 h	10.06 ± 0.29 c–f	3.27 ± 0.01 b–d
T_{10}	NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	24.95 ± 0.29 b–e	54.34 ± 0.34 cd	53.95 ± 0.59 e	3.57 ± 0.02 bc	10.92 ± 0.46 a–c	3.29 ± 0.03 a–d
T_{11}	NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha),	24.55 ± 0.34 de	52.88 ± 0.85 d–f	49.59 ± 0.60 g	3.03 ± 0.07 f–h	10.48 ± 0.21 a–e	3.24 ± 0.06 b–f
T_{12}	NP + VC and EC (75% + 2.5 t/ha and 2.5 t/ha)	24.67 ± 0.33 c–e	55.72 ± 1.07 bc	57.16 ± 0.50 cd	3.45 ± 0.08 cd	10.56 ± 0.25 a–d	3.32 ± 0.03 ab
T_{13}	NP + VC and EC (50% + 2.5 t/ha and 2.5 t/ha)	24.30 ± 0.49 e–g	51.18 ± 0.48 fg	52.60 ± 1.09 f	3.26 ± 0.07 d–f	10.30 ± 0.41 b–f	3.26 ± 0.02 b–e
T_{14}	NP + VC and EC + PGPR (75% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha)	26.19 ± 0.06 a	53.57 ± 0.45 de	58.82 ± 0.20 b	4.02 ± 0.09 a	11.62 ± 0.32 a	3.36 ± 0.03 a
T_{15}	NP + VC and EC + PGPR (50% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha)	25.48 ± 0.21 a–c	51.09 ± 0.30 fg	51.90 ± 1.36 f	3.70 ± 0.15 b	11.29 ± 0.35 ab	3.29 ± 0.04 a–c
	Significance	***	***	***	***	***	***

RDFs: Recommended dose of fertilizers; FYM: farmyard manure; NP: nitrogen and phosphorus; VC: vermicompost; PGPR: plant-growth-promoting rhizobacteria; EC: enriched compost. Different letters within each column indicate significant differences according to Tukey's HSD test. *** Significant difference parameters indicated by Tukey's HSD test at $p \leq 0.05$. Data are given as mean ± SE.

3.2. Differential Effects of Assimilated Nutrient Management on the Yielding Attributes

The different assimilated nutrients had substantial effects on yielding attributes. Table 3 represents the effects of assimilated nutrient management on the yielding attributes. The module with 75 percent NP and organic mixtures of VC and EC (both 2.5 t/ha) along with PGPR (5 kg/ha) recorded the maximum polar as well as equatorial diameters of the cabbage head. However, the variations for the polar diameter were insignificant, whereas the equatorial diameter varied significantly among different assimilated modules (Table 3). In capsicum, the largest fruit size, number of fruits, and unit weight were observed for the 75 percent NP and organic mixtures of VC + EC (both 2.5 t/ha) + PGPR, which determined the largest head in cabbage. In addition, the highest unit gross root weight in radish was observed for the 75 percent NP and organic mixtures of VC and EC (both 2.5 t/ha) + PGPR. The module 75 percent NP and organic combinations of VC+ EC (both 2.5 t/ha) along with PGPR (5 kg/ha), which achieved the maximum output in cabbage, followed by capsicum and radish, considerably outperformed the RPF, which produced roughly 365.25, 260.63, and 192.47 q per ha in the aforementioned three crops, respectively. The crops experienced a significant increase in yield percentage when treated with a combination of 75% NP and organic mixtures of VC and EC (both 2.5 t/ha) + PGPR (5 kg/ha). The increases in yield percentage were 29.32%, 41.10%, and 31.12%, respectively, compared to the standard practice. Overall, the application of the module 75 percent NP and organic mixtures of VC and EC (both 2.5 t/ha) coupled with PGPR (5 kg/ha) promoted the yielding attributes.

Table 3. Differential effects of assimilated nutrient management on the yielding attribute parameters in cabbage, capsicum, and radish-based cropping sequence.

Code	Treatment Details	Cabbage			Capsicum					Radish	
		Polar Diameter (cm)	**Equatorial Diameter (cm)**	**Yield/ha (q)**	**Fruit Length (cm)**	**Fruit Breadth (cm)**	**Number of Fruits**	**Fruit Weight (g)**	**Yield/ ha (q)**	**Root Weight (g)**	**Yield /ha (q)**
T_1	RDFs + FYM (Control)	11.34 ± 0.13 g	13.21 ± 0.19 a	365.25 ± 9.55 d–f	5.33 ± 0.15 fg	4.81 ± 0.19 ef	19.87 ± 0.03 ef	47.92 ± 1.00 de	260.64 ± 8.37 e–g	72.79 ± 2.23 c–e	192.47 ± 5.89 c-e
T_2	NP + VC (75% + 2.5 t/ha)	11.56 ± 0.06 c	13.23 ± 0.14 a	393.73 ± 9.19 bc	5.88 ± 0.11 a–c	5.01 ± 0.29 b–d	21.84 ± 0.69 cd	50.25 ± 1.69 b–d	307.77 ± 2.68 cd	61.63 ± 2.96 e–g	162.98 ± 7.83 e-g
T_3	NP + VC (50% + 2.5 t/ha)	11.15 ± 0.02 m	12.33 ± 0.31 f	357.67 ± 10.30 e–g	5.51 ± 0.09 ef	4.84 ± 0.24 ef	19.52 ± 0.77 e–g	47.32 ± 1.41 de	257.11 ± 8.30 fg	51.24 ± 2.26 g	135.51 ± 5.97 g
T_4	NP + EC (75% + 2.5 t/ha)	11.55 ± 0.22 d	13.11 ± 0.09 ab	351.87 ± 4.65 e–g	5.33 ± 0.08 fg	4.85 ± 0.21 ef	20.12 ± 0.75 d–f	49.25 ± 1.13 b–e	271.04 ± 4.24 ef	64.81 ± 0.87 d–f	171.37 ± 2.30 d-f
T_5	NP + EC (50% + 2.5 t/ha)	11.18 ± 0.39 k	12.98 ± 0.21 a–d	322.10 ± 6.59 h	5.03 ± 0.04 h	4.18 ± 0.02 ef	18.66 ± 1.05 fg	47.63 ± 0.88 de	251.24 ± 4.88 g	54.92 ± 3.42 fg	145.23 ± 9.04 fg
T_6	NP + PGPR (75% + 5 kg/ha)	11.61 ± 0.25 b	13.01 ± 0.23 a–c	395.74 ± 13.09 bc	6.00 ± 0.09 a–c	4.95 ± 0.35 c–e	24.59 ± 1.09 b	51.51 ± 0.70 bc	321.96 ± 5.28 bc	67.63 ± 3.11 c–e	178.85 ± 8.22 c-e
T_7	NP + PGPR (50% + 5 kg/ha)	11.42 ± 0.37 f	12.96 ± 0.21 a–e	369.23 ± 5.40 c–f	5.81 ± 0.07 b–d	5.02 ± 0.22 b–d	20.10 ± 1.03 d–f	48.61 ± 0.26 c–e	268.75 ± 6.40 ef	66.45 ± 4.92 d–f	175.71 ± 13.01 d-f
T_8	NP + VC + PGPR (75% + 2.5 t/ha + 5 kg/ha)	11.21 ± 0.19 j	12.52 ± 0.29 d–f	388.99 ± 10.20 b–d	5.78 ± 0.14 cd	4.92 ± 0.21 d–f	20.45 ± 1.09 d–f	47.45 ± 2.33 de	323.83 ± 4.66 b	76.75 ± 2.75 b–d	202.95 ± 7.28 b-d
T_9	NP + VC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	11.15 ± 0.10 m	12.21 ± 0.14 f	347.48 ± 9.08 f–h	5.46 ± 0.06 ef	4.80 ± 0.21 ef	19.19 ± 0.62 fg	46.22 ± 0.38 e	262.87 ± 4.28 e–g	75.42 ± 6.01 b–d	199.43 ± 15.88 b-d
T_{10}	NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	11.17 ± 0.19 l	12.66 ± 0.20 b–f	379.11 ± 1.23 c–e	5.59 ± 0.08 de	4.86 ± 0.24 ef	19.79 ± 0.37 ef	48.91 ± 2.22 c–e	273.28 ± 9.38 e	79.49 ± 5.33 bc	210.20 ± 14.11 bc
T_{11}	NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	11.04 ± 0.11 n	12.52 ± 0.17 d–f	335.50 ± 6.47 gh	5.14 ± 0.14 gh	4.77 ± 0.29 f	17.75 ± 0.57 g	47.95 ± 1.57 de	227.65 ± 8.18 h	71.32 ± 3.29 c–e	188.59 ± 8.70 c-e
T_{12}	NP +VC and EC (75% + 2.5 t/ha and 2.5 t/ha)	11.25 ± 0.38 i	12.55 ± 0.05 c–f	396.61 ± 9.38 bc	5.87 ± 0.12 a–c	5.07 ± 0.21 bc	21.31 ± 0.84 c–e	52.39 ± 1.09 ab	301.67 ± 7.23 d	86.55 ± 6.35 ab	228.88 ± 16.81 ab
T_{13}	NP + VC and EC (50% + 2.5 t/ha and 2.5 t/ha)	11.31 ± 0.14 h	12.51 ± 0.09 ef	336.34 ± 19.49 gh	5.46 ± 0.02 ef	4.91 ± 0.26 d–f	20.09 ± 0.38 d–f	48.95 ± 1.93 c–e	268.92 ± 11.61 ef	73.95 ± 4.88 c–e	195.56 ± 12.92 c-e
T_{14}	NP + VC and EC + PGPR (75% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha)	12.18 ± 0.03 a	13.12 ± 0.07 ab	472.35 ± 9.79 a	6.10 ± 0.05 a	5.26 ± 0.26 a	27.22 ± 0.38 a	54.92 ± 2.37 a	367.74 ± 3.07 a	95.43 ± 5.47 a	252.36 ± 14.47 a
T_{15}	NP + VC and EC + PGPR (50% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha)	11.50 ± 0.38 e	12.56 ± 0.07 c–f	408.66 ± 4.60 b	6.06 ± 0.08 ab	5.11 ± 0.26 ab	22.73 ± 0.54 bc	50.37 ± 0.94 b–d	313.71 ± 10.98 b–d	94.68 ± 4.58 a	250.39 ± 12.12 a
	Significance	*NS*	***	***	***	***	***	***	***	***	***

RDFs: Recommended dose of fertilizers; FYM: farmyard manure; NP: nitrogen and phosphorus; VC: vermicompost; PGPR: plant-growth-promoting rhizobacteria; EC: enriched compost. Different letters within each column indicate significant differences according to Tukey's HSD test. NS: non-significant; *** significant difference parameters indicated by Tukey's HSD test at $p \leq 0.05$. Data are given as mean ± SE.

3.3. Differential Effects of Assimilated Nutrient Management on the Physicochemical Attributes

The various assimilated nutrients had significant effects on the physicochemical attributes. The effect of absorbed nutrient management on yield parameters is shown in Table 4. Protein and ascorbic acid were shown to be the best quality features in cabbage using an integrated schedule comprising 75 percent NP + VC and EC (both 2.5 t/ha) along with PGPR (5 kg/ha). With an assimilated schedule consisting of 75 percent NP + VC and EC (both 2.5 t/ha) along with PGPR (5 kg/ha), the quality attributes of total soluble solids and ascorbic acid were observed to be the best in capsicum. In radish crops, ascorbic acid and total soluble solids were observed to be best when they were using the schedule which included 50 percent NP + VC and EC (both 2.5 t/ha) along with PGPR (5 kg/ha). In our study, TSSs and vitamin C were substantially, or at least significantly, higher with decreased inorganics (50%) compared to larger inorganic concentrations (75 or 100%), irrespective of the type of biological applied or the presence or absence of bacteria inoculation. In our study, independent of the type of organic amendment or bacterial inoculation, TSSs and ascorbic acid were significantly, or at least statistically, greater in soils with reduced inorganic content (50%) compared to soils with higher inorganic content (75 or 100%). The integrated module comprising 75 percent NP + VC and EC (both 2.5 t/ha) along with PGPR (5 kg/ha) promoted the physicochemical properties of sequential crops.

Table 4. Differential effects of assimilated nutrient management on the quality parameters in cabbage–capsicum–radish-based cropping sequence.

Code	Treatment Details	Cabbage		Capsicum		Radish	
		Protein (%)	Ascorbic Acid (mg/100 g)	TSSs (^{0}Brix)	Ascorbic Acid (mg/100 g)	TSSs (^{0}Brix)	Ascorbic Acid (mg/100 g)
T_1	RDFs + FYM (Control)	16.44 ± 0.61 b–d	11.91 ± 0.36 g	4.53 ± 0.03 g	164.43 ± 1.18 e	2.67 ± 0.17 g	29.69 ± 0.90 e–h
T_2	NP + VC (75% + 2.5 t/ha)	15.59 ± 0.25 e–g	12.96 ± 0.87 d–f	4.77 ± 0.09 d–f	165.58 ± 0.75 de	3.17 ± 0.17 f	30.10 ± 0.61 ef
T_3	NP + VC (50% + 2.5 t/ha)	15.04 ± 0.12 gh	13.48 ± 0.62 d	5.00 ± 0.10 bc	167.24 ± 2.45 c–e	3.83 ± 0.17 c	31.91 ± 1.36 bc
T_4	NP + EC (75% + 2.5 t/ha)	14.87 ± 0.52 h	12.39 ± 0.36 fg	4.67 ± 0.09 fg	161.39 ± 1.29 f	3.80 ± 0.15 cd	29.81 ± 0.25 e–h
T_5	NP + EC (50% + 2.5 t/ha)	14.14 ± 0.62 i	13.26 ± 0.48 de	4.90 ± 0.06 c–e	166.51 ± 3.29 c–e	3.17 ± 0.17 f	30.39 ± 0.58 de
T_6	NP + PGPR (75% + 5 kg/ha)	15.86 ± 0.24 d–f	12.08 ± 0.65 g	4.73 ± 0.09 e–g	166.02 ± 2.28 c–e	3.67 ± 0.17 d	30.41 ± 0.71 de
T_7	NP + PGPR (50% + 5 kg/ha)	15.18 ± 0.45 gh	14.38 ± 0.79 c	4.97 ± 0.12 cd	167.69 ± 1.45 cd	3.33 ± 0.17 e	30.87 ± 1.02 b–e
T_8	NP + VC + PGPR (75% + 2.5 t/ha + 5 kg/ha)	16.52 ± 0.33 bc	12.78 ± 0.18 ef	4.67 ± 0.09 fg	164.91 ± 1.29 de	3.67 ± 0.17 d	28.63 ± 0.09 h
T_9	NP + VC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	15.65 ± 0.62 e–g	15.05 ± 0.16 bc	4.83 ± 0.09 cd–f	165.14 ± 1.37 de	3.33 ± 0.17 e	29.97 ± 0.0.90 e–g
T_{10}	NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	16.35 ± 0.39 cd	13.02 ± 0.29 d–f	4.67 ± 0.17 fg	167.19 ± 2.20 c–e	3.33 ± 0.17 e	28.77 ± 0.0.32 gh
T_{11}	NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha),	15.50 ± 0.29 f–h	15.32 ± 0.38 ab	4.93 ± 0.03 cd	165.11 ± 2.35 de	3.17 ± 0.17 f	30.73 ± 1.24 c–e
T_{12}	NP +VC and EC (75% + 2.5 t/ha and 2.5 t/ha)	16.19 ± 0.91 c–e	12.92 ± 0.43 d–f	4.80 ± 0.06 d–f	168.81 ± 1.05 bc	3.67 ± 0.67 d	29.10 ± 0.40 f–h
T_{13}	NP + VC and EC (50% + 2.5 t/ha and 2.5 t/ha)	15.21 ± 0.14 gh	14.98 ± 0.16 bc	4.90 ± 0.06 c–e	170.84 ± 0.56 ab	3.33 ± 0.17 e	31.47 ± 1.41 b–d
T_{14}	NP + VC and EC + PGPR (75% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha)	17.39 ± 0.38 a	15.78 ± 0.29 a	5.20 ± 0.06 a	172.13 ± 1.61 a	4.03 ± 0.02 b	32.07 ± 0.77 ab
T_{15}	NP + VC and EC + PGPR (50% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha)	17.02 ± 0.47 ab	15.62 ± 0.54 ab	5.17 ± 0.12 ab	171.38 ± 1.98 ab	4.17 ± 0.17 a	33.15 ± 0.20 a
	Significance	***	***	***	***	***	***

RDFs: Recommended dose of fertilizers; FYM: farmyard manure; NP: nitrogen and phosphorus; VC: vermicompost; PGPR: plant-growth-promoting rhizobacteria; EC: enriched compost. Different letters within each column indicate significant differences according to Tukey's HSD test; *** significant difference parameters indicated by Tukey's HSD test at $p \leq 0.05$. Data are given as mean ± SE.

3.4. Differential Effects of Assimilated Nutrient Management on the Cost Economics

Table 5 indicates the findings regarding the effects of assimilated nutrient management on cost economics. The economic analysis involved the treatment combination of 75 percent NP + VC and EC (both 2.5 t/ha) in addition to PGPR (5 kg/ha). The cultivation of crops in a specific sequence, namely cabbage–capsicum–radish, yielded the highest output and generated an annual net return of INR 11.24 lacs per hectare, with a benefit–cost ratio of 2.35, as compared to other treatment modules, including RPN. The RPN treatment module, for instance, yielded an annual return of INR 8.06 lacs and a B:C ratio of 2.00, which was lower than the aforementioned sequence.

Table 5. Differential effects of assimilated nutrient management on economic analysis in cabbage–capsicum–radish-based cropping sequence.

Code	Treatment Details	Annual Benefit	
		Net Return (INR in Lacs)	Benefit–Cost Ratio
T_1	RDFs + FYM (Control)	8.06	2.00 ± 0.05 a–d
T_2	NP + VC (75% + 2.5 t/ha)	7.64	1.47 ± 0.01 fg
T_3	NP + VC (50% + 2.5 t/ha)	5.95	1.16 ± 0.02 c–i
T_4	NP + EC (75% + 2.5 t/ha)	7.59	1.77 ± 0.04 bc
T_5	NP + EC (50% + 2.5 t/ha)	6.56	1.57 ± 0.04 c–e
T_6	NP + PGPR (75% + 5 kg/ha)	9.16	2.23 ± 0.04 ab
T_7	NP + PGPR (50% + 5 kg/ha)	7.84	1.96 ± 0.02 a–e
T_8	NP + VC + PGPR (75% + 2.5 t/ha + 5 kg/ha)	8.39	1.58 ± 0.01 cd
T_9	NP + VC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	6.73	1.29 ± 0.01 b–h
T_{10}	NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha)	8.41	1.93 ± 0.02 a–f
T_{11}	NP + EC + PGPR (50% + 2.5 t/ha + 5 kg/ha),	6.75	1.58 ± 0.04 cd
T_{12}	NP + VC and EC (75% + 2.5 t/ha and 2.5 t/ha)	9.07	1.93 ± 0.04 a–f
T_{13}	NP + VC and EC (50% + 2.5 t/ha and 2.5 t/ha)	7.28	1.56 ± 0.02 c–f
T_{14}	NP + VC and EC + PGPR (75% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha)	11.24	2.35 ± 0.02 a
T_{15}	NP + VC and EC + PGPR (50% + 2.5 t/ha and 2.5 t/ha + 5 kg/ha)	9.60	2.04 ± 0.04 a–c
	Significance		***

RDFs: Recommended dose of fertilizers; FYM: farmyard manure; NP: nitrogen and phosphorus; VC: vermicompost; PGPR: plant-growth-promoting rhizobacteria; EC: enriched compost. Different letters within each column indicate significant differences according to Tukey's HSD test. NS: Non-significant; ***: significant difference parameters indicated by Tukey's HSD test at $p \leq 0.05$. Data are given as mean ± SE.

4. Discussion

Without optimal nutrition, crop production would suffer from a lack of fertilizer, which might also have an impact on quality and growth output. Yet, the physiochemical characteristics of the soil may be diminished by the use of synthetic or chemical fertilizers. A variety of nutrient replacements with organic amendments must be used to improve the quality of the soil and sustain its health. In this work, the field was used to plant radish, cabbage, and capsicum in the order specified by the procedures for assimilating nutrients. We used organic amendments and bio-inoculants to decrease the need for synthetic fertilizers (nitrogen and phosphorus). Through the use of absorbed nutrient management, various growth, yield quality, and economic benefits were seen.

The balanced nutrition given to the crop during its critical stages may be the reason why the application of various organic amendments significantly changed its distinct growth qualities. The plant height results for cabbage were consistent with earlier findings for broccoli and cauliflower by Bhardwaj et al. [8] and Sharma et al. [9]. In addition, our findings regarding plant spread were entirely consistent with those of Sharma and Chandra [10] and Choudhary and Choudhary [11] for Brassicaceae crops. When evaluating the INM system in a cauliflower, French beans, and okra module, Sharma et al. [12] discovered that an INM practice using 20 t/ha vermicompost along with 75 percent NPK as well as PGPR resulted in the maximum vegetative growth in each crop. The recommended practice of 20 t/ha of farmyard manure with RDN 100 percent was comparable to the first but much better than NPK at the rate of 50:40:50 kg per ha applied alone. Similar vegetative growth results in pepper were also consistent with earlier findings in sweet pepper published by Flores et al. [13], Escalona and Pire [14], and Fawzy et al. [15]. Kumar et al. [16] also discovered that combining inorganic 75 percent NPK coupled with 25 percent organic (VC) nutrients improved the root length in carrots. With an application of half RDFs + half of the advised FYM (10 t per ha) + rhizosphere bacteria (Azotobacter + PSB each 5 kg per ha), the maximum root length and root diameter in carrots was obtained, as opposed to RDFs (80N:60P:60K), which recorded 18.18 and 2.90 cm of length and diameter, respectively [17].

Similar to the current study, all the researchers in these studies attributed the improvement in vegetative growth observed through the application of inorganic NPK to amelioration of inorganic N, which is a vital constituent of protein content and chlorophyll. This may have increased the foliage, thus enhancing photosynthesis, ultimately leading to high biomass production. It might be because nitrogen fertilizers cause cells to enlarge. As a component of amino acids, DNA, coenzymes, phytohormones, and alkaloids, N promotes cell growth, expansion, and division. The increases in nitrogen levels that were observed can be attributed to intensified efforts in vermicomposting and plant bio-inoculation. These efforts facilitated the production of growth-promoting substances, prolonged nutrient availability during the crop growth cycle, improved photosynthetic processes, and ultimately led to an increase in biomass yield [18]. The aforementioned results were consistent with the findings made by El-Shimi et al. [19] in *Capsicum* spp., Kondapa et al. [20] in chili, Jadhav et al. [21] in *Raphanus sativus*, and Vithwel and Kanaujia [22] in *Daucaus carota*.

The yield in the three crops often increased substantially with the recommended practice (100% NPK) when 25% of the specified amount of NP was switched to both EC and VC organic manures coupled with PGPR for the respective crop's seeds or seedlings. The results suggest that inorganics (NP) can be reduced by up to 25% by substituting them with organic manures and bio-inoculating with PGPR. In terms of producing qualities and yield, the conclusions presented by an earlier study are consistent with those of the current examination. Meena et al. [23] produced the highest curd production (21.91 t/ha) by applying neem cake 1.5 t per ha, vermicompost 2.5 t per ha coupled with azotobacter 2 kg per ha, and 75 percent of the recommended dose of NPK inorganic fertilizer; this recommendation saves 25 percent of the synthetic fertilizer normally used. Similar results were found by Sharma et al. [12] for cauliflower, French beans, and okra, and they discovered that vermicompost (20 t/ha) and 75 percent of the NPK combined with PGPR produced the highest yield, resulting in a net savings of 25 percent of the NPK fertilizers and average increases in yield of 9.46, 2.36, and 1.14 percent, respectively, over the recommended dose of fertilizers. A high yield of green chilies was seen, as previously recorded by Rani et al. [24], when 150 percent of the recommended N sources were provided along with the application of FYM, neem cake, and vermicompost in the ratio of 25:25:50, respectively. The enhanced production of fruit in the chili plants was attributed to the ameliorative solubilization impact and nutrient availability resulting from the incorporation of organic matter. Additionally, heightened physiological activity facilitated the accumulation of adequate food reserves for the developing sinks and improved allocation towards the maturing fruits. Patil et al. [25] showed a considerably greater root yield of carrot by using RDFs, FYM, and vermicompost in a ratio of 50:25:25. The increase in protein content in the aforementioned treatments may have resulted from the addition of P-solubilizing rhizobacteria, specifically *Bacillus* sp., which may have increased N and P uptake and ameliorated the production of phytohormones like auxins and gibberellins [8–10,26]. A plant produces more proteins and fewer carbohydrates when it is exposed to more nitrogen. The plot with the lowest ascorbic acid concentration was obtained when the recommended dose of NPK and FYM (125:110:50 kg per ha + 20 t/ha) was applied. Increased chemical fertilization lowers ascorbic acid content because plants respond to nitrogen exposure by producing more proteins and fewer carbohydrates. Vitamin C is produced using carbohydrates, so its synthesis may have diminished. The content of ascorbic acid in carrots increased when different organic manures were used in place of inorganic fertilizer, according to Kumar et al. [16]. As natural manure is less expensive than synthetic fertilizer, the cost of the finished product may change. The cropping sequence of cauliflower, French beans, and okra with vermicompost (20 t/ha) plus 75% of the advised concentration of NPK along with PGPR produced the highest annual net returns, according to Sharma et al. [12], as opposed to the advised practice of NPK + 20 t FYM per ha, which produced INR 1.8 lacs per hectare. To the best of our knowledge, this is the first study of the cropping sequence of capsicum, radish, and cabbage using INM along with PGPR in the Northwestern Himalayan region. Future studies will attempt to use INM coupled with PGPR on microbial and soil communities to ameliorate the growth of the plant.

5. Conclusions

Therefore, it can be concluded that 75 percent nitrogen and phosphorus, and organic mixtures of VC and EC (both 2.5 t/ha) coupled with PGPR (5 kg/ha), improved growth, increased yield, and provided the highest annual return in the mid-hills of the northwestern Himalayas. Consequently, this assimilated combination, along with the entire recommended FYM and K_2O as a base dose, can be recommended as the most cost-efficient mixture for achieving a greater yield on a sustainable basis. Moreover, 75 percent nitrogen and phosphorus, and organic mixtures of VC and EC (both 2.5 t/ha) coupled with PGPR (5 kg per ha), led to a 25% reduction in the use of nitrogen and phosphorus fertilizers. This sequence could be advantageous to the farmer for the year-round production of various vegetables without leaving the field fallow. The results of integrated nutrient management of the cabbage–capsicum–radish cropping sequence with fertilizers and plant-growth-promoting rhizobacteria in terms of growth parameters, yield, and biochemical parameters can be seen in the behavior of each crop versus the control.

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