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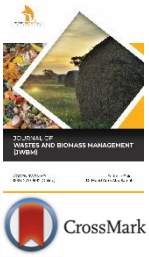

RESEARCH ARTICLE

EFFECTS OF ORGANIC AND BIO-FERTILIZERS ON GROWTH AND YIELD PERFORMANCE OF LEAFY VEGETABLES

Acharya Balkrishna[a,b,c], Ajay Kumar Gautam[a,c*], Nidhi Sharma[a], Vedpriya Arya[a,b], Vikram Khelwade[a]

[a] Patanjali Herbal Research Department, Patanjali Research Institute, Haridwar 249405, India
[b] Department of Allied Sciences, University of Patanjali, Haridwar 249405, India
[c] Patanjali Organic Research Institute (PORI), Padartha, Laksar Road Haridwar-249404, India
**Corresponding author email: ajay.gautam@patanjali.res.in*

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ABSTRACT

The use of organic and bio-fertilizers and high-yielding crop varieties has increased in recent years. These fertilizers have emerged as the best and environment-friendly alternative to the chemical fertilizers. The present study was conducted to study the effects of organic and bio-fertilizers on the growth and yield performance of leafy vegetables. Three vegetable crops namely coriander (*Coriandrum sativum*), rye (*Brassica nigra*), and fenugreek (*Trigonella foenum-graecum*) and six treatments were assessed in this study under field conditions. The results demonstrated growth and yield-promoting effects upon the combined use of organic and bio-fertilizers on leafy vegetables. Treatments like Dharti ka Chaukidar combined with Patanjali Gibbrika (T2), and Pori Potash combined with Rhizo Plus (T5) emerged as highly effective combinations, offering superior results in plant growth and productivity. The practice of organic farming not only improves soil health but also plant physiological attributes, such as relative growth rate (RGR), net assimilation rate (NAR), and leaf area ratio (LAR), depicting their multifaceted role in sustainable crop management. The present study, therefore, provides compelling evidence to support their widespread adoption in modern agriculture, paving the way for a sustainable and resilient farming future.

KEYWORDS

leafy vegetables, organic and bio-fertilizers, soil health, growth, yield

1. INTRODUCTION

Indian agriculture has gained significant momentum recently because of the widespread use of quality fertilizers and high-yielding crop varieties (Creamer et al., 2022). With the growing concerns over the detrimental effects of chemical fertilizers on the environment and human health, their excessive use has also been linked to the depletion of soil organic matter, reduction in microbial diversity, and potential health risks associated with the accumulation of harmful substances in food products (Tal, 2018; Bisht and Chauhan, 2020; Singh et al., 2021). It stressed that the concept of soil quality should look at the importance of system maintenance instead of soil fertility and maximum production. The term soil quality has been used to measure soil fitness to support crop growth without its degradation (Singh et al., 2019; Bhatt et al., 2019; Creamer et al., 2022). Organic farming has emerged as a suitable solution to improve soil quality and make it fit for crop growth and development. Organic fertilizers have now been considered a viable alternative, offering the potential to enhance soil health, reduce environmental pollution, and improve crop productivity (Manna et al., 2021).

By improving soil fertility and structure, applying organic fertilizers has tremendous effects on the growth and yield performance of different food and vegetable crops. Their use significantly changes cation exchange capacity (CEC) and enhances soil organic carbon and other nutrients for soil microbes and growing plants. The stability of earthworm communities has been found more pronounced in soils amended with organic manure (Bertrand et al., 2015; Zhou et al., 2022). With the adverse effects of the long-term use of chemical fertilizers on soil properties, several studies have reported improved soil properties along with enhanced plant growth and final yields when using organic fertilizers. The quality of organic produce has drawn the attention of producers and consumers towards the use of organic and bio-fertilizers in farming systems. The beneficial effects of organic and bio-fertilizers on leafy vegetable crops have been reported in numerous earlier studies (Mkhabela et al., 2020; Ye et al., 2022).

The coriander, fenugreek, and mustard are economically significant crops widely cultivated for their culinary, medicinal, and industrial applications (Ramkumar and Karuppusamy, 2021; Kaushik and Barmanray, 2022). These crops are highly valued for their unique flavors, nutritional profiles, and diverse uses in various industries, including food, pharmaceuticals, and cosmetics (Ramkumar and Karuppusamy, 2021). However, achieving optimal biomass and yield in these crops while adhering to sustainable agricultural practices remains a challenge. The use of organic fertilizers may offer a promising solution by providing essential nutrients and improving soil physical, chemical, and biological properties. These organic amendments have been shown to enhance soil structure, water-holding capacity, and microbial activity, leading to improved nutrient availability and uptake by plants (Diacono and Montemurro, 2011; Aytenew and Bore, 2020). Based on such observations, the present study was formulated to investigate the potential of various organic fertilizers on the growth and yield of coriander, fenugreek, and mustard crops (Rai) cultivated simultaneously during the same season. By evaluating the performance of these crops under different organic fertilizer regimes, this research seeks to identify the most effective fertilization strategies for optimizing crop productivity while promoting sustainable agricultural practices.

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2. Material and Methods

2.1 Site description

The experimental field trial site of the present study is located at Patanjali Organic Research Institute Private Limited (PORI), village Padartha in Uttarakhand, India (29.8304° N, 78.1222° E and 271 m (889.108 ft.) above sea level). These field trials were conducted between October to December 2023 [(Rye: 05.10.2023 to 07.12.2023); (Fenugreek: 05.10.2023 to 20.12.2023) and Coriander: 14.10.2023 to 20.12.2023)]. The average total precipitation during the field study was recorded at 11.63mm with 35°C maximum and 7°C minimum temperature. Soil properties were also determined per the standard procedures (Jackson, 1973).

2.2 Experimental Design

The experiment for the three vegetable crops namely coriander (*Coriandrum sativum*), rye (*Brassica nigra*), and fenugreek (*Trigonella foenum-graecum*) was arranged in a split-plot design with three replications, and two factors in a Randomized Block Design (RBD). The line-sowing method was used to sow seeds following all recommended agronomic practices. To avoid the attack of any soil-borne pathogens, the seeds were treated overnight with bio-pesticide (*Trichoderma* sp. and *Pseudomonas* sp. @ 5ml/liter each). The proposed fertilizer treatments were used at each 30-day interval after sowing. Detailed information on individual treatments and their combinations used in the present experimentation are given below in Table 1.

Table 1: Detailed information on different treatments used in the present study

Treatments	Treatment Detail		
	Coriander	Rye	Fenugreek
T0 (Control)	No fertilizer	No fertilizer	No fertilizer
T1	Jaivik Khad + Patanjali Gibbrika	Jaivik Khad + Patanjali Azoto plus	Jaivik Khad + Rhizo Plus
T2	Dharti ka Chaukidar + Patanjali Gibbrika	Dharti ka Chaukidar + Patanjali Azoto plus	Dharti ka Chaukidar + Rhizo Plus
T3	Jaivik Prom + Patanjali Gibbrika	Jaivik Prom + Patanjali Azoto plus	Jaivik Prom + Rhizo Plus
T4	Poshak + Patanjali Gibbrika	Poshak + Patanjali Azoto plus	Poshak + Rhizo Plus
T5	Pori Potash + Patanjali Gibbrika	Pori Potash + Patanjali Azoto plus	Pori Potash + Rhizo Plus
T6	Patanjali Gibbrika	Patanjali Azoto plus	Rhizo Plus

2.3 Field sampling and processing

Total nine healthy plants for each vegetable crop were selected from each treatment and their replicates and analyzed for different plant parameters. The common parameters including growth (height, biomass, chlorophyll, etc.) and yield were evaluated to study the effects of test fertilizers at 30 and 60 days after sowing (DAS). The total chlorophyll content was measured with the help of the SPAD meter and expressed as the SPAD meter value. The Net Assimilation Rate (NAR), Relative Growth Rate (RGR) and Leaf Area Ratio (LAR) were calculated by using the following formula:

$$\textit{Net Assimilation Rate} = (W_2 - W_1)/(t_2 - t_1) \times (\ln(LA_2) - \ln(LA_1))/(A_2 - A_1)$$

Where, W_2 and W1 are plant dry weights at times t_1 and t_2, $\log LA_2$ and $\log LA_1$ are the natural logs of leaf areas A_1 and A_2 at times t_1 and t_2.

$$\textit{Relative Growth Rate (RGR)} = \ln(W_2) - \ln(W_1)/t_2 - t_1$$

Where, W_1= Fresh weight at time t_1(30 days), W_2= Fresh weight at the time t_2 (60 days), t_1= 30 days, t_2 = 60 days and $t_2 - t_1$=30 days (since the interval is from 30 to 60 days).

$$\textit{Leaf Area Ratio (LAR)} = [LA_2 / W_2 + LA_1 / W_1] / 2$$

Where, W_1= Dry weight at time t_1 (30 days), W_2= Dry weight at the time t_2 (60 days), leaf areas LA_1 and LA_2 at times t1 and t2.

2.4 Statistical analysis

Data obtained after analysis of each parameter are presented as mean± standard deviation (SD) of nine replicates. One-way ANOVA with Dunnett's multiple comparisons test was performed using GraphPad Prism version 8.02 for Windows.

3. Results

The results of the present study revealed that all fertilizers have altered the chemical properties of soil significantly. All treatments over control enhanced total and available nutrients, indicating an effect of organic fertilizers on chemical properties. Apart from the positive impact on soil characteristics, all the treatments were also effective in improving experimental crops' growth and yield characteristics.

3.1 Plant length (Shoot and root length)

In the present study, organic fertilizers significantly affected plant length (expressed as shoot and root length). The highest shoot length was recorded in rye (29.88cm) which was followed by coriander (21.44cm) and fenugreek (17.66cm) after 30 days of sowing. Here treatment T4 (Poshak + Patanjali Gibbrika) performed well in coriander, Pori Potash + Patanjali Azoto plus (T5) in rye and Pori Potash + Rhizo Plus (T5) in fenugreek. After 60 days of sowing, the shoot length was found highest in rye (57.22cm), coriander (46.78cm) and fenugreek (26.66cm). The effects of treatments were found considerable as Jaivik Prom + Patanjali Gibbrika (T3) in coriander, Patanjali Azoto Plus (T6) in rye and Pori Potash + Rhizo Plus (T5) in fenugreek (Table 2).

In the case of root length, it was recorded highest at 13.44cm (in rye), followed by 9.50cm (fenugreek) and 7.25cm in coriander after 30 days of sowing. The treatments like Pori Potash + Patanjali Gibbrika (T5), Jaivik Khad + Patanjali Azoto plus (T1) and Pori Potash + Rhizo Plus (T5) have been found effective in coriander, rye and fenugreek respectively. Similarly, after 60 days of sowing, the highest root length was observed in coriander (15.55cm), rai (14.11) and fenugreek (9.88cm). During this period, treatment Jaivik Prom + Patanjali Gibbrika (T3), Patanjali Azoto Plus (T6) and Poshak + Rhizo Plus (T4) have shown their best performance on root length of coriander, rye and fenugreek respectively (Table 3).

Table 2: Effect of organic fertilizers and bio-fertilizers on plant length (shoot length) of leafy vegetables (coriander, rye and fenugreek).

Treatments	Shoot Length (30 days)			Shoot Length (60 days)		
	Coriander	Rye	Fenugreek	Coriander	Rye	Fenugreek
T0	15.31±3.65	24.33± 0.88	13.22± 1.96	40.78±3.34	50.22± 5.87	19.67± 0.88
T1	20.75±1.58**	26.11± 3.03**	13.61± 2.69	40.89±1.26	56.67± 4.81	24.67± 1.20**
T2	20.72±1.92**	29.44± 1.34**	16.56± 2.41*	41.56±3.35	59.00± 4.58*	23.22± 2.59**

Table 2(Cons) : Effect of organic fertilizers and bio-fertilizers on plant length (shoot length) of leafy vegetables (coriander, rye and fenugreek).						
T3	21.78±2.08**	29.00± 4.67**	14.22± 1.64	46.78±4.35**	53.00± 6.57	24.22± 1.17**
T4	21.44±1.35**	29.00± 0.67**	15.67± 1.67	45.44±5.60*	56.44± 9.10	25.44± 3.03**
T5	21.33±1.04**	29.89± 1.17**	17.67± 3.49**	42.00±2.40	55.89± 2.78	26.67± 1.67**
T6	20.56±2.21**	28.56± 1.17**	13.89± 0.65	43.89±4.16	57.22± 7.63	20.44± 1.50**

Mean ± standard deviation of nine replicates. * Significant (p≤0.50); ** Highly significant (p≤0.01)

Table 3: Effect of organic fertilizers and bio-fertilizers on plant length (Root length) of leafy vegetables (coriander, rye and fenugreek).						
Treatments	**Root Length (30 days)**			**Root Length (60 days)**		
	Coriander	**Rye**	**Fenugreek**	**Coriander**	**Rye**	**Fenugreek**
T0	5.33±0.58	8.78±0.69	6.67±1.48	12.00±1.15	11.67± 1.15	8.33±0.67
T1	5.46±1.10	13.44±1.07**	7.78±1.95	12.11±0.51	13.89± 2.67*	9.33±1.33
T2	5.83±1.04	11.33±1.73**	8.22±0.69*	12.78±1.84	12.78± 0.69	9.44± 0.38
T3	5.78±1.55	10.44±0.96*	7.22±0.67	15.56±1.51**	12.56± 1.26	9.67± 0.33*
T4	5.56±0.69	10.00±1.67	8.17±0.73*	15.33±1.73**	11.89± 1.89	9.89±0.38*
T5	7.25±1.08**	11.22±1.39**	9.50±1.17**	13.67±2.31	12.44± 0.69	9.22±1.17
T6	6.67±1.36	9.39±0.86	8.72±0.79**	13.00±1.00	14.11± 2.21*	8.56± 1.39

Mean ± standard deviation of nine replicates. * Significant (p≤0. 50); ** Highly significant (p≤0.01)

3.2 Leaf area and Number of leaves per Plant

The effects of fertilizer treatments on leaf area were shown maximum by Dharti ka Chaukidar + Patanjali Gibbrika (T2) in coriander (11.69 cm^2), and Jaivik Prom + Patanjali Azoto plus (T3) in rye (168.44cm^2) after 30 days of sowing. After 60 days of sowing, the maximum leaf area was recorded in coriander (17.16cm^2) with treatment Jaivik Prom + Patanjali Gibbrika (T3), rye (529.44 cm2) Jaivik Khad + Patanjali Azoto plus (T1) while Dharti ka Chaukidar + Rhizo plus (T2) in fenugreek (8.23cm^2) (Table 4).

3.3 Chlorophyll Content

Enhancement in chlorophyll content was recorded in all three crops treated with different fertilizer treatments. The chlorophyll content was increased up to 43.17 in rye treated with Patanjali Azoto plus (T5), to 34.87 in coriander under Jaivik Prom + Patanjali Gibbrika (T3) treatment and to 38.74 in fenugreek with Dharti ka Chaukidar (T2) treatment after 30 days of sowing. In the later stages at 60 days after sowing, the Jaivik Khad + Rhizo Plus (T1) in fenugreek, Jaivik Prom + Patanjali Azoto plus (T3) in rai and Jaivik Khad + Patanjali Gibbrika (T1) in coriander were observed effectively in enhancing chlorophyll content 43.20, 38.39 and 35.81 respectively (Table 4).

Table 4: Effect of organic fertilizers and bio-fertilizers on leaf area and chlorophyll content of leafy vegetables (coriander, rye and fenugreek).						
Treatments	**Leaf Area (60 days)**			**Chlorophyll Content (60 days)**		
	Coriander	**Rye**	**Fenugreek**	**Coriander**	**Rye**	**Fenugreek**
T0	9.72±3.42	304.89±44.20	5.50±1.80	30.47±1.04	35.42±3.96	37.18±2.44
T1	8.55±1.41	529.44±265.64*	7.14±1.66	35.81±1.87*	37.33±1.21	43.20±3.40**
T2	9.47±1.37	456.55±85.19	8.23±1.92**	33.82±1.78	37.26±0.39	37.64±0.88
T3	17.16±2.61**	485.44±17.53	7.94±1.59*	31.06±1.65	38.39±4.57	38.29±2.27
T4	14.94±0.82**	464.56±134.07	6.78±1.59	31.32±3.05	36.72±1.88	41.48±3.74**
T5	13.55±1.75**	485.67±257.39	8.17±1.77**	34.23±7.97	35.43±2.12	38.87±3.69
T6	10.61±1.98	494.00±144.83	5.72±0.53	31.14±2.57	36.46±1.64	40.21±5.25

Mean ± standard deviation of nine replicates. * Significant (p≤0. 50); ** Highly significant (p≤0.01)

3.4 Shoot Biomass

The results of the fresh and dry weight of the shoot are expressed in the form of shoot biomass. An enhancement in both fresh and dry shoot weight was observed which reflected the positive effects of all treatments on shoot biomass. The treatments Pori Poshak + Patanjali Gibbrika (T4) coriander (11.16gm), Pori Potash + Patanjali Azoto plus (T5) in rye (3.30 gm) and Rhizo Plus (T6) in fenugreek (0.72 gm) were found effective in increasing shoot biomass after 30 days of sowing. Similarly, after 60 days of sowing, treatments like Dharti ka Chaukidar + Patanjali Gibbrika (T2), Jaivik Prom + Patanjali Azoto Plus (T3) and Pori Potash + Rhizo Plus (T5) were found effective in increasing shoot biomass 35.25 gm,16.93 gm and 2.78 gm in rye, coriander and fenugreek respectively (Table 5).

3.5 Total yield

An enhancement in yield per plot was recorded with the application of fertilizer treatments in all three experimental crops. The maximum yield in coriander was recorded (3.17 kg) under treatment Patanjali Gibbrika (T6), in the rye (7.27 kg) in Pori Potash + Patanjali Azoto plus (T5) treatment and in fenugreek (7.33 kg) with treatment Pori Potash + Rhizo Plus (T5) after 30 days of sowing. The enhancement in yield was also found to increase after 60 days of sowing. It was found 7.87 kg in coriander treated with Patanjali Gibbrika (T6), 15.60 kg in rye under Pori Potash + Patanjali Azoto plus (T5) as treatment and 27.26 kgin fenugreek treated with Pori Potash + Rhizo Plus (T5) (Table 5, Figure 1).

Table 5: Effect of organic fertilizers and bio-fertilizers on Shoot Biomass and Total yield of leafy vegetables (coriander, rye and fenugreek).						
Treatments	**Shoot Biomass (60 days)**			**Total Yield (60 days)**		
	Coriander	**Rye**	**Fenugreek**	**Coriander**	**Rye**	**Fenugreek**
T0	13.91±2.01	12.107± 2.56	1.730± 0.02	5.67±1.40	7.03±3.56	8.00±2.39
T1	14.04±2.31	30.572± 15.21**	1.198± 0.42	5.90±1.27	13.40±4.89**	22.83±1.19**
T2	16.93±2.84*	34.642± 5.98**	2.477± 0.29**	7.57±0.83**	13.90±3.97**	26.25±0.35**

Table 5 (Cons) : Effect of organic fertilizers and bio-fertilizers on Shoot Biomass and Total yield of leafy vegetables (coriander, rye and fenugreek).						
T3	13.91±1.31	35.241± 4.84**	2.363± 0.25**	7.13±0.61**	14.80±7.54**	20.67±2.46**
T4	14.84±1.97	30.086± 13.45**	2.692± 0.14**	7.50±0.60**	11.00±1.56	21.83±3.40**
T5	15.19±1.34	27.692± 14.86*	2.787± 0.40**	6.77±0.15*	15.60±3.32**	27.26±2.66**
T6	14.71±0.65	28.778± 10.37**	2.618± 0.32**	7.87±0.55**	14.03±4.32**	10.00±1.32

Mean ± standard deviation of nine replicates. * Significant (p≤0.50); ** Highly significant (p≤0.01)

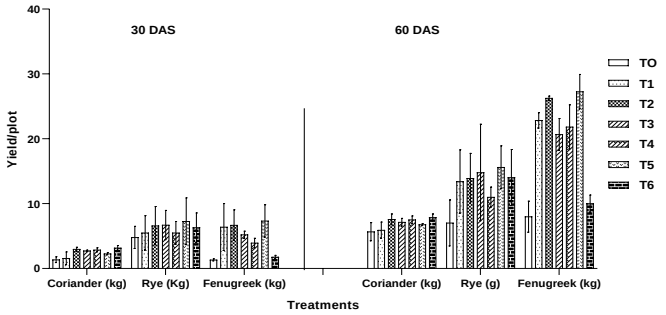

Figure 1: Effect of organic fertilizers and bio-fertilizers on total yield of leafy vegetables (Coriander, Rye and Fenugreek).

3.6 Net Assimilation Rate (NAR)

The results of the Net Assimilation Rate (NAR) in coriander revealed that the treatment T2 (Dharti ka Chaukidar + Patanjali Gibbrika) showed the best performance, with the highest NAR of 0.00821 gm/cm^2/day, followed by T4 (Poshak + Patanjali Gibbrika). Both of these treatments show significantly higher NAR values than others, indicating that they are highly effective in promoting plant growth. In the case of rye, the treatment T2 (Dharti ka Chaukidar + Patanjali Azoto Plus) has the highest NAR of 0.00394 gm/cm^2/day, indicating that this treatment is the most effective for promoting the growth and biomass accumulation of Rye. T3 (Jaivik Prom + Patanjali Azoto Plus) and T4 (Poshak + Patanjali Azoto Plus) also show relatively high NAR values of 0.00354 and 0.00344 gm/cm^2/day, respectively, suggesting that both Jaivik Prom (which likely provides phosphorus and other nutrients) and Poshak (a mycorrhiza-based biofertilizer) are effective in enhancing the growth of Rai. T0 (Control) has the lowest NAR of 0.00175 gm/cm^2/day, which is expected due to the absence of fertilizer, leading to limited growth and assimilation. The NAR in fenugreek was observed in plants under treatment of Dharti ka Chaukidar + Rhizo Plus (T2) with the highest NAR value of 0.00800 gm/cm^2/day, suggesting this treatment has the most efficient nutrient assimilation rate over the 30 days. Other treatments like T4 (Poshak + Rhizo Plus) and T1 (Jaivik Khad + Rhizo Plus) also showed high NAR values, 0.00598 gm/cm^2/day and 0.00554 gm/cm^2/day, respectively, indicating their good growth performance due to the combined application of biofertilizers. The lowest NAR of 0.000645 gm/cm^2/day showed by T6 (Rhizo Plus) reflected that Rhizo Plus alone did not significantly enhance the growth of fenugreek compared to the other treatments that included additional bio-fertilizers (Figure 2).

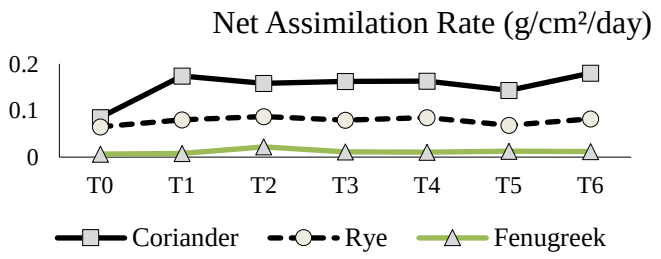

Figure 2: Effect of organic fertilizers and bio-fertilizers on Net Assimilation Rate (NAR) of leafy vegetables (Coriander, Rye and Fenugreek).

3.7 Relative Growth Rate (RGR)

The RGR is the rate of increase of dry weight per unit weight already present per unit time. The treatment T6 shows the highest RGR of 0.180 g/day, indicating it is the most effective in promoting shoot growth among all treatments. Despite being a standalone treatment, its high RGR suggests that the formulation of Gibbrika is highly beneficial to coriander growth. T1 and T2 also show relatively high RGRs, indicating that these combinations of organic fertilizers and Gibbrika also promote growth, though not as effectively as T6. T3 and T4 both show similar results (0.162 and 0.163 RGR, respectively). Likewise, in rye, the treatment T2 is the most effective treatment for enhancing growth as it exhibited the highest RGR of 0.087 g/day. It showed the best performance in promoting the fresh shoot weight over the 30 days, likely due to the synergistic effects of the organic fertilizer which supports nitrogen fixation and enhances root and shoot growth. T4 and T6 are the next best treatments, with RGRs of 0.085 and 0.082, respectively. Both treatments show effective growth stimulation. T5 treatment had a relatively low RGR (0.0686 per day), which might indicate that potassium alone is insufficient for optimal growth. The effects of fertilizer treatment on the Relative Growth Rate (RGR) of Fenugreek also demonstrated their positive effects. The treatment T2 demonstrated the best results in terms of RGR (0.0220 per day), likely due to its combination of organic manure and neem-based amendments, which enhanced soil fertility and pest resistance. T5 also showed promising results (0.0130 per day), highlighting the importance of potassium in improving plant growth (Figure 3).

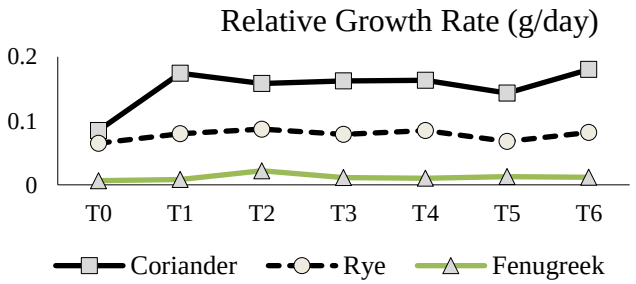

Figure 3: Effect of organic fertilizers and bio-fertilizers on Relative Growth Rate (RGR) of leafy vegetables (Coriander, Rye and Fenugreek).

3.8 Leaf Area Ratio (LAR)

The Leaf Area Ratio (LAR) is expressed in terms of the ratio between the total leaf area to the plant biomass per plant and also gets positive impacts during the study. In the coriander crop, treatment T1 showed the highest LAR of 48.215 cm^2/g, indicating that this treatment provides the highest leafiness relative to its dry weight. This suggests that Jaivik Khad (organic manure) combined with Patanjali Gibbrika (a biofertilizer) improves the leaf area relative to the dry matter more than other treatments. The increase in leaf area at 30 days and a considerable increase in shoot dry weight by 60 days indicates robust vegetative growth. T5 (Pori Potash + Patanjali Gibbrika) has a LAR of 37.895 cm^2/g, which is also quite high, showing that the addition of potash (from molasses) along with the biofertilizer enhances leaf area, although not as much as T1. T2 (Dharti ka Chaukidar + Patanjali Gibbrika) and T6 (Patanjali Gibbrika) show moderate LAR values (34.445 cm^2/g and 31.705 cm^2/g respectively), reflecting good leaf area development but not as significant as T1.

The results of LAR in Rye revealed that the control was found better (40.85 cm^2/g), but this may indicate poor biomass accumulation despite the large leaf area. T1 and T2 have LARs of 37.3 and 31.05 cm^2/g, respectively. T1 shows relatively higher leafiness compared to T2, reflecting the positive effects of organic manures like Jaivik Khad, which are combined with the biofertilizer Patanjali Azoto Plus. This combination may help to improve nutrient uptake and enhance photosynthesis efficiency. T3 and T4 show LARs of 31.8 and 33.85 cm^2/g, respectively. Both treatments show relatively similar leaf area development but are not as effective as T1 in terms of leaf area for the dry weight, likely due to the nature of the different organic fertilizers used.

In fenugreek, the treatment T2 (Dharti ka Chaukidar + Rhizo Plus) demonstrated the highest Leaf Area Ratio (LAR) of 4.67 cm^2/g, making it the most effective treatment for promoting leaf area relative to dry weight. This suggests that the combination of Jaivik Khad (organic fertilizer) and Rhizo Plus (bio-fertilizer) is particularly efficient in supporting leaf growth without a proportional increase in biomass, which can enhance photosynthetic capacity. Treatments like T3 and T4 also showed effective results with LARs of 4.28 cm^2/g and 4.30 cm^2/g, respectively, indicating strong leaf area development balanced with biomass accumulation. T1 and T5 exhibit moderate LARs of 3.90 cm^2/g and 4.39 cm^2/g, respectively, suggesting that while they support good leaf growth, they are not as effective as T2 in optimizing leaf area relative to dry weight. T6**,** with a LAR of 4.25 cm^2/g, reflects moderate leaf area development but falls behind treatments with organic fertilizers in terms of leaf efficiency.

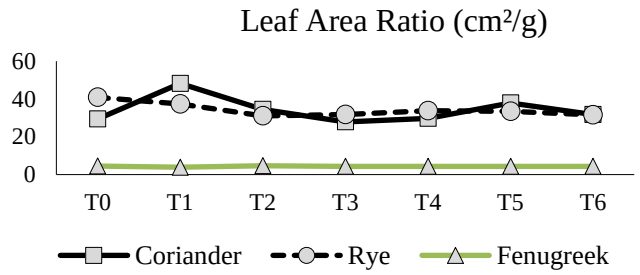

Figure 4: Effect of organic fertilizers and bio-fertilizers on Leaf Area Ratio (LAR) of leafy vegetables (Coriander, Rye and Fenugreek).

4. Discussion

Results from the present study on using organic treatments on coriander, rye, and fenugreek revealed improvement in their growth and yield. Despite having positive impacts on growth and yield, these treatments also showed efficacy in improving soil characteristics. It has been reported in previous studies that organic fertilizers can support the growth and yield of cop plants even at later stages of their growth and development. This might be due to their slow-release potential which ensures their availability even for longer-duration crops (Lin et al., 2023; Balkrishna et al., 2023). In addition, the multiplication of beneficial microbes applied with organic fertilizers might also have proved supportive in plant growth and development (Wei et al., 2024). Based on such assumptions, it is now established that the use of organic farming provides not only balanced nutritional nitrogen (N), phosphorus (P), and potassium (K) to the plant, but also heals degraded soil and protects users and consumers from harmful effects of chemical fertilizers (Parewa et al., 2019; Jote et al., 2023).

The application of Jaivik Prom and Pori Potash along with bio-fertilizers like Patanjali Gibbrika, Azoto plus and Rhizo plus has been proven beneficial for shoot length enhancement in all crops. The application of prom has already been reported as a crop enhancer on many crops like wheat, capsicum, coepea, pea, etc. (Balkrishna et al., 2024 a, b, c, d). Similarly, the application of potash-rich fertilizers is also reported as a crop growth and yield promoter (Rawat et al., 2016; Balkrishna et al., 2023). In addition, the bio-fertilizers also aided the performance of organic fertilizers on the overall growth and performance of experimental crops. The multiplication of microbes available in bio-fertilizers are important source of soluble nutrients in the soil and makes them available for growing plants (Wei et al., 2024; Balkrishna et al., 2023). That's why, the combination of organic and bio-fertilizers is found considerably fruitful in the present study in comparison to their use singly. In addition to plant length, the combination of organic and bio-fertilizers also posed positive impacts on other growth parameters. All fertilizers supported the root growth in comparison to the control which depicted their ability to provide balanced nutrition of N, P and K (Shaji et al., 2021). Although all fertilizers promote the formation of chlorophyll content, the plants under the treatment of Jaivik Khad and Jaivik Prom synthesize it maximum which describes the importance of these treatments for crop development. With the formation of chlorophyll, more leaf area was observed in crop plants growing under treatments which ultimately affected the final yield of the experimental crops (Senthil Kumar and Ganesh, 2022).

RGR is a measure of how rapidly a plant increases its biomass, and it generally correlates with NAR, as both reflect how well the plant is converting resources into growth. Treatments that promote higher RGR typically also show higher NAR, indicating that the plant is efficiently using available nutrients for biomass production. In coriander, a high RGR usually correlates with a high NAR because the plant is effectively converting resources into growth. Similarly, plants with a high LAR typically have greater leaf area to capture sunlight, which supports a higher NAR and thus higher RGR (Perez-Harguindeguy et al., 2013). In Coriander, treatments like T1 (Jaivik Khad + Patanjali Gibbrika) and T2 (Dharti ka Chaukidar + Patanjali Gibbrika) show that combining organic fertilizers with biofertilizers (like Patanjali Gibbrika) optimizes leaf production (LAR) and photosynthetic efficiency (NAR), leading to increased biomass production (RGR). However, T1 demonstrates better leaf area development (higher LAR), showing that a combination of organic fertilizers can optimize leaf area and photosynthetic capacity, even if the RGR is slightly lower. Similarly, in rye, the interrelationship between RGR, NAR, and LAR highlights how different treatments influence the overall growth and efficiency of plants. For example, T2 (Dharti ka Chaukidar + Patanjali Azoto Plus) shows both the highest RGR and NAR, indicating that the combination of organic fertilizers with a bio-fertilizer (Azoto Plus) enhances both photosynthetic efficiency and biomass accumulation. Although T0 (Control) had the highest LAR, it did not result in increased biomass, suggesting that while the plant produced more leaves, it was unable to efficiently convert them into growth due to nutrient limitations. On the other hand, treatments like T1 and T2 showed a more balanced growth strategy, where leaf area and biomass accumulation were both optimized. These findings suggest that treatments combining organic fertilizers with bio-fertilizers (such as Azoto Plus) provide the best results for maximizing plant growth, making them effective for sustainable agricultural practices. T5 while supporting some growth, showed lower efficiency, suggesting that potassium alone is not as effective without a broader spectrum of nutrients. The synergy between RGR, NAR, and LAR in fenugreek is evident across the treatments in fenugreek. T2 (Dharti ka Chaukidar + Rhizo Plus) stands out as the most effective treatment in promoting plant growth, nutrient assimilation, and leaf area development. The combination of organic inputs and bio-fertilizers optimizes all three parameters, demonstrating the importance of integrated nutrient management for enhancing plant performance. These findings underscore the value of integrated organic fertilizer approaches for maximizing the growth and yield of leafy vegetables. The application of organic fertilizers along with bio-fertilizers during the present study appears to be a highly effective strategy for enhancing both growth and yield. While Patanjali Gibbrika is an effective source of gibberellic acid, other bio-fertilizers like Azoto Plus and Rhizo Plus are also equipped with beneficial microbes with excellent plant growth-promoting ability (Balkrishna et al., 2023). The effects of these microbes have also been studied earlier on different crops, validating the results of the present study. In addition, the presence of natural biocides like neem oil may also help improve plant health by reducing pest pressure, further supporting efficient growth and nutrient use. The combination of organic and biofertilizers can enhance nitrogen fixation and optimize plant growth by improving nutrient availability and photosynthesis efficiency (Erturk et al., 2010; Tairo and Ndakidemi, 2013; Islayed et al., 2020; Wei et al., 2024). Moreover, the application of phosphorus and mycorrhiza-based bio-fertilizers is reported to be effective in enhancing growth and yield (Mohamed et al., 2021; Balkrishna et al., 2024 a, b).

Several previous studies have investigated the performance of different organic and bio-fertilizers on various crops and crop systems. A study carried out to assess the effect of biofertilizer and organic fertilization on growth, nutrient contents and fresh yield of dill (*Anethum graveolens*) proposed the replacement of chemical fertilizers with organic sources supplemented by NPK Symbion is possible (Islayed et al., 2020). Other studies of organic fertilizers' effect on Pear-jujube also reflected their growth and yield-promoting potential (Ye et al., 2022). Another study by a group researcher evaluated the effects of organic fertilizer on mixed crops (wheat-maize) and found their potential to promote yield, soil quality, and soil fauna-feeding activity (Zhou et al., 2022). Similar studies on many agricultural and horticultural crops also recorded similar findings on organic agriculture (Zandvakili et al., 2019; Balkrishna et al., 2024 a, b; Ollio et al., 2024; Verma and Verma, 2012; Khandaker et al., 2017; Balkrishna et al., 2024 c, d). These studies also supported the research findings of the present study and highlighted the use of organic fertilizers with their potential to promote the growth and yield of various crops. In conclusion, organic fertilizers can enhance the growth of leafy vegetables. Their application can also maintain the soil nutrient ratio and microbial population. However, more research is still required to formulate organic and bio-fertilizers more precisely so that their efficacy on all types of crops can be stabilized and enhanced.

5. Conclusion

This study demonstrates that the combined application of organic and bio-fertilizers significantly enhances the growth and yield performance of leafy vegetables, including coriander, rye, and fenugreek. By improving key parameters such as shoot and root length, chlorophyll content, leaf

area, shoot biomass, and total yield, these fertilizers provide a sustainable alternative to conventional chemical fertilizers. Treatments such as Dharti ka Chaukidar combined with Patanjali Gibbrika (T2), and Pori Potash combined with Rhizo Plus (T5), emerged as highly effective, offering superior results in plant growth and productivity. The findings highlight the potential of organic amendments to enhance soil fertility, nutrient availability, and microbial activity, thus promoting a balanced ecosystem for optimal plant development. Organic fertilizers improved not only soil health but also plant physiological attributes, such as relative growth rate (RGR), net assimilation rate (NAR), and leaf area ratio (LAR), showcasing their multifaceted role in sustainable crop management. Notably, the integration of bio-fertilizers with organic amendments enhanced the availability of essential nutrients like nitrogen, phosphorus, and potassium, and stimulated beneficial microbial activity. This synergistic effect contributed to robust plant growth, efficient photosynthesis, and greater resilience to environmental stresses, underscoring the effectiveness of combining organic and bio-fertilizers over their individual use. In conclusion, the integration of organic and bio-fertilizers presents a viable, eco-friendly approach to enhancing the growth and yield of leafy vegetables while preserving soil and environmental health.

Conflicts Of Interest

The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript.

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