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Biostimulant-Mediated Root-Shoot Growth Dynamics and Vegetative Biomass Response in Coriander (*Coriandrum sativum* l.)

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Abstract

Coriander (Coriandrum sativum L.) is an annual spice herb having leaves and seeds as their economic part. This study explored the idea of using bio-stimulants, an environmentally friendly nutrient supplier and stress-tolerant factor. Among three different bio-stimulants viz., Phytocil®, Humic acid and Seaweed granules used to study their effects on growth, biochemical and herbage yield parameters in Coriander (Coriandrum sativum L.) CO (CR) 4, observed results revealed the use of Phytocil® bio-stimulant, either individually or in combination with other bio-stimulants to possess significant outcomes compared to the control. This suggests that the use of bio-stimulant can increase the overall value of coriander by enhancing its yield, resulting in high economic value even under stress and varying climatic conditions.

Keywords: Bio-stimulants, Phytocil, Coriander, Humic acid, Seaweed

INTRODUCTION

Coriander (*Coriandrum sativum* L.) Apiaceae, is an annual herb cultivated worldwide for its fresh leaves and dried fruit which are used extensively in spice flavouring agent and raw material for essential oil and oleoresin industries (Patel and Jain, 2025). India is the major centre for coriander production and consumption. According to latest projections, coriander area remains relatively stable between 2023–24 and 2024–25, while the production increased substantially. With almost 57.5% of the country's production in 2024–25, Madhya Pradesh continues to be the leading producer of coriander (Indian Agri, 2024-2025). Gujarat and Rajasthan are also key production hubs, highlighting the concentration of commercial coriander agriculture in central and western India.

Fresh coriander foliage is consumed as a leafy vegetable and to garnish. It is nutritionally rich in vitamin A, vitamin C, minerals and dietary fibre, while dried coriander schizocarps are

rich in proteins, carbs, crude fibre and aromatic oil (Al-Khayri et al., 2023). The availability of nutrients, crop management strategies and environmental variables all have a significant impact on coriander output and quality (Da Costa et al., 2019; Serri et al., 2021 and Madhavan et al., 2025;). However, relying heavily on chemical fertilizers to boost crop output can lead to soil deterioration, nutritional imbalances, higher production costs and environmental concerns, emphasizing the importance of sustainable crop nutrition techniques.

Bio-stimulants have gained great attention as sustainable agricultural inputs for improving crop growth, nutrient use efficiency and overall plant performance. They complement conventional nutrient management practices by stimulating physiological and metabolic processes associated with plant development, nutrient acquisition and stress responses (Arinaitwe et al., 2025 and Hassanein et al., 2022). Various bio-stimulant sources, including humic substances, seaweed and silicon, have been explored for their potential to support plant growth and productivity. Their influence on plant development may vary depending on the nature of the bio-stimulants, application method, crop species and prevailing environmental conditions (Yuan and Dickinson, 2024).

Humic substances (HS), are important bio-stimulants that promote root development, nutrient uptake and plant metabolic activity. Their effects are associated with improved nutrient acquisition, root growth and physiological regulation, including stimulation of photosynthesis and antioxidant defence (Da Silva et al., 2019 and Hassanein et al., 2021).

Seaweed extracts are important plant biostimulants rich in bioactive compounds such as polysaccharides, phytohormones, amino acids, betaines, phenolics and minerals, which can promote plant growth, nutrient uptake and physiological activity (Ali et al., 2021; Battacharyya et al., 2015 and Mughunth et al., 2024). Seaweed application can also enhance root development, photosynthetic performance and productivity while improving tolerance to abiotic stresses such as salinity, drought and temperature extremes (Ali et al., 2021 and Battacharyya et al., 2015).

Silicon and protein hydrolysates are being recognised as a promising bio-stimulant for improving plant growth, nutrient use efficiency, and tolerance to environmental stresses. Silicon application can enhance plant performance under stress by improving nutrient balance, Na^+/K^+ homeostasis, photosynthetic efficiency and antioxidant defence mechanisms. Protein hydrolysates can stimulate carbon and nitrogen metabolism, nutrient uptake and nutrient-use efficiency through their amino acids and peptides (Al-Garni et al., 2019 and Colla et al., 2017).

Foliar application of Si improved growth, chlorophyll content, relative water content and essential oil production under salinity, demonstrating its potential to alleviate stress-induced physiological limitations (Amiripour et al., 2021).

In coriander (*Coriandrum sativum* L.), the integration of bio-stimulants into crop management practices offers an opportunity to improve vegetative growth, biomass accumulation and yield while supporting more efficient and sustainable production systems (Ghasemi Tabasi et al., 2025 and Serri et al., 2021).

MATERIALS AND METHODS

Experimental site: The study was carried out at College Orchard, Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu agricultural University, Coimbatore located at located at 11°00"N, 76°55"E at 411m MSL during the period of 2023-24. Coriander variety CO (CR) 4 available at Department of Spices and Plantation Crops, HC&RI, TNAU, were sown in lines with spacing of 20 x 15cm, at a rate of 60g per bed (3m X 3m).

Details of bio-stimulants used: In this study, three different bio-stimulants from BioNature® viz., Humic acid (2%), seaweed granule extract (0.09%) and Phytocil® (1%), were used to determine the variation in physiology and yield of coriander variety CO (CR) 4. The biostimulants were prepared according to the treatment specifications and uniformly applied to plot surfaces in the morning hours at 15 DAS and 30 DAS for coriander CO(CR) 4. Phytocil® from BioNature® was utilized at a concentration of 1 per cent for experimental purposes.

Methodology**:** The experiment was conducted for one season to study the effects of bio-stimulants on herbage yield of coriander CO (CR) 4 during spring season.. It was conducted in an open environment, with the experiment set up using a Randomized Block Design (RBD) consisting of 8 treatments (Table 1) replicated three times. Each plot measured 3.0m x 3.0m. Before field preparation, the plots were treated with farmyard manure (FYM) at a rate of 10 tons per hectare.

Treatment details**:** Treatment and combinations used are Humic acid 2%, Seaweed extract 0.09% , Phytocil 1% , Humic acid + Phytocil , Seaweed extract + Phytocil, Humic acid + Seaweed extract, Humic acid + Seaweed extract + Phytocil and control.The treatments were imposed through Soil topping twice at 15 and 30 days after sowing (DAS).

The biostimulants used and their concentrations are given below.

Bio-stimulant	Active Ingredient	Concentration
Humic acid	Humic acid	2%
	Qs	98%
Seaweed granule	Seaweed extract	0.09%
	Qs	99.91%
Phytocil	Protein hydrolysate	1%
	SiO_2 Amorphous clay	99%

***Biometric observations*:** Physiological, biochemical, and yield parameters were evaluated at specific time intervals following sowing. Physiological assessments included measuring plant height (cm) from ground level to the main stem apex of five randomly selected plants at 35 days after sowing (DAS), and determining shoot and root lengths at 30 and 40 DAS. Leaf area per plant (cm^2) was quantified using a Leaf Area Meter at 40 DAS, while the Leaf Area Index (LAI) was calculated at 30 DAS based on the formula proposed by Williams (1946), dividing the leaf area per plant (cm^2) by the occupied ground area (cm^2). Biochemically, total chlorophyll content was estimated across all treatments and replications at 40 DAS using a Soil Plant Analysis Development (SPAD) meter. Finally, yield-related data, specifically the fresh and dry weights of both roots and shoots, were documented for analysis at 30 and 40 DAS.

***Statistical analysis*:** Statistical analysis was performed on growth and yield data obtained from a Randomized Block Design (RBD) experiment with 8 treatments and 3 replications. Analysis of Variance (ANOVA) (Panse and Sukhatme, 1967) was conducted to determine significant differences among treatments. Critical Difference (CD), Standard Error of Difference (SED), Standard Error of Mean Difference (SEm) values were calculated and reported to assess the statistical significance of treatment effects. These values help determine the minimum difference required between treatment means to be considered statistically significant. All statistical analyses were performed using IBM SPSS statistics (version 27) at a 5 % probability level ($p < 0.05$).

Statistical analysis for allometry evaluation: Root-shoot biomass relationships were evaluated using fresh and dry biomass data recorded at harvest. Fresh weight of root and shoot were taken separately in g/plant. They were then dried in a hot air oven at 65-70°C to record dry weight of

shoot and root. Root biomass was regressed against herbage biomass using the power-law equation (Marks, 1978), $Y=aX^b$.

The linear equation,

$$\ln(Y) = \ln(a) + b \ln(X)$$

where,

b - Allometric coefficient
ln(a) - Intercept

The linear regression in ln-transformed data was used to estimate the allometric coefficient (b), intercept (ln(a)), coefficient of determination (R^2) and significance. These were fitted in separate allometric relationships for fresh and dry biomass assessment. The allometric coefficient $b<1$, $b=1$, $b>1$ was interpreted as positive allometry, isometry and negative allometry, respectively (Klingenberg, 1996). The relationships were visualized using regression curves with 95% confidence intervals and statistical analyses were performed using R software version 4.4.0.

RESULTS AND DISCUSSION

The experiment was carried out in an open field at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. Coriander (*Coriandrum sativum* L.) CO (CR) 4 seeds were sown and the application of bio-stimulant was given as soil topping to increase growth and yield. The experiment was carried out to evaluate the effect of different bio-stimulants, either individually or in combination (Table 1.), on the growth and yield of coriander CO (CR) 4. The outcomes of the experiment were taken in replicates and the average was recorded.

Effect of bio-stimulants on physiological and biochemical parameters

In all 8 different treatments, including the control (Table 1.), the plant height was significantly different among them. In T4, where Phytocil® and Humic acid® were used in combination, showed increased plant height (36.37 cm). This is followed by T3 (Phytocil®) as 33.17 cm and the lowest height was recorded in T1 (Humic acid) as 24.11 cm and T8 (Control) as 24.51 cm (Table 3.). This shows that the bio-stimulant Phytocil® will have a positive impact on the growth of coriander at the vegetative stage.

Table 1. Effect of bio-stimulants on Plan height

Treatments	**Plant height in cm (35 DAS)**
T1	24.11
T2	28.16
T3	33.17
T4	36.37
T5	26.05
T6	30.31
T7	30.75
T8	24.51
SEd	**0.95**
CD @ 5%	**2.05**

The height of the shoot and root were measured by plucking out three random plants from each replicated field at 30 and 40 DAS and the average was recorded. A significant difference was observed between plants from different treatments at 30 DAS (Figure 1.) and 40 DAS (Figure 2.)



Fig. 1: Shoot-root growth of Coriander CO (CR) 4 at 30 DAS



Fig.2: Shoot-root growth of Coriander CO (CR) 4 at 40 DAS

Focusing on the leaves, which were harvested as the economic part, bio-stimulants had their own effects on the leaf area, leaf area index and also on chlorophyll content.

The leaf area was measured as maximum and minimum in T4 (Phytocil® and Humic acid®) and T8 (Control) as 42.33 cm^2 and 36.28 cm^2 (Table 4). The treatments T3 (Phytocil®), T5 (Seaweed extract + Phytocil®) and T6 (Humic acid®+ Seaweed extract) also had a significant increase in leaf area. This clearly showed that the effect of Phytocil® was highly efficient in herbage quality (Figure 3.).

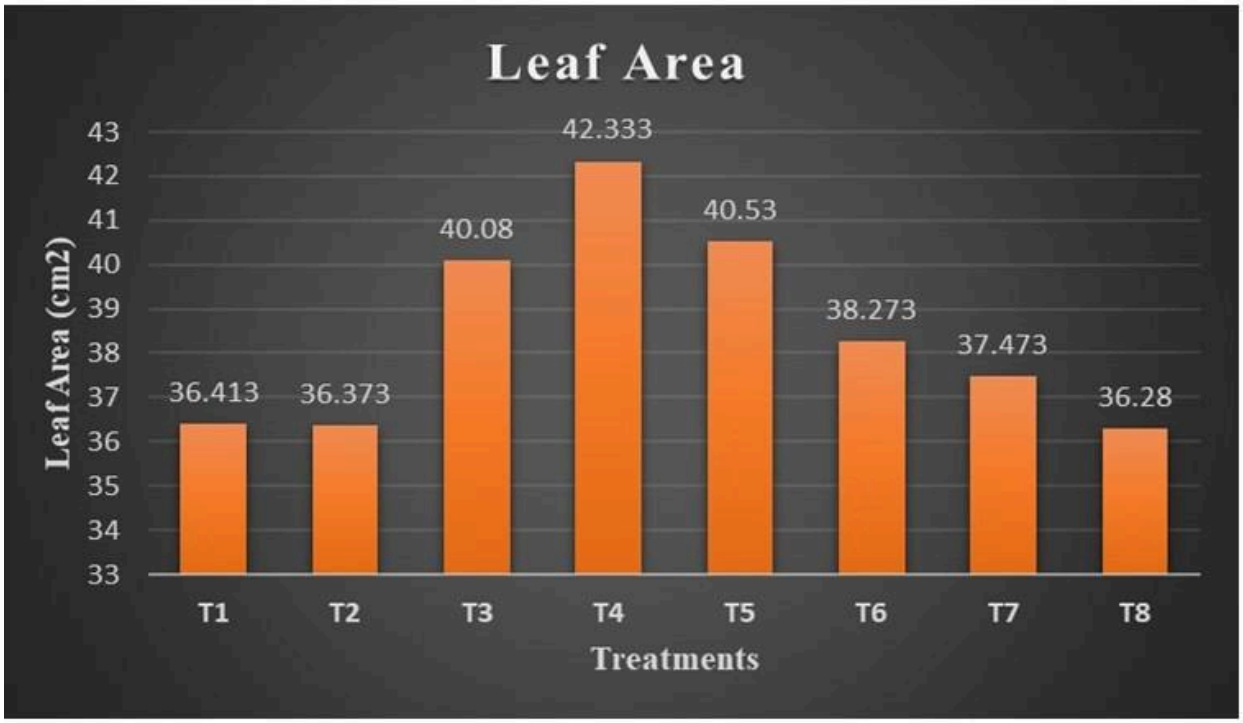


Fig. 3: Graph representing the difference in Leaf Area of Coriander CO (CR) 4 at 40 DAS in different treatments

Leaf Area Index (LAI) was measured as maximum and minimum of 0.14 (T4 (Phytocil® and Humic acid®) and T5 (Seaweed extract + Humic acid®) and 0.12 (T1 (Humic acid®), T2 (Seaweed extract), T7 (Phytocil® + Humic acid® + Seaweed extract) and T8 (Control)). The results were significant and the overall result represents the effective efficiency of Phytocil® on herbage quality (Table 4.; Figure 4.).



Fig. 4: Graph representing the difference in Leaf Area Index of Coriander CO (CR) 4 at 40 DAS in different treatments

The chlorophyll content, which is the main parameter to increase the herbage yield, was calculated using a SPAD (Soil Plant Analysis Development) meter. The highest recorded data was 30.63 in T4 (Phytocil and Humic acid), which is followed by T6 (Humic acid extract + Seaweed extract) and T3 (Phytocil). The lowest chlorophyll content was recorded in T8 (control) (Table 4.). There was a significant increase in chlorophyll content by the application of bio-stimulants, which would reflect their role in herbage yield (Figure 5.).

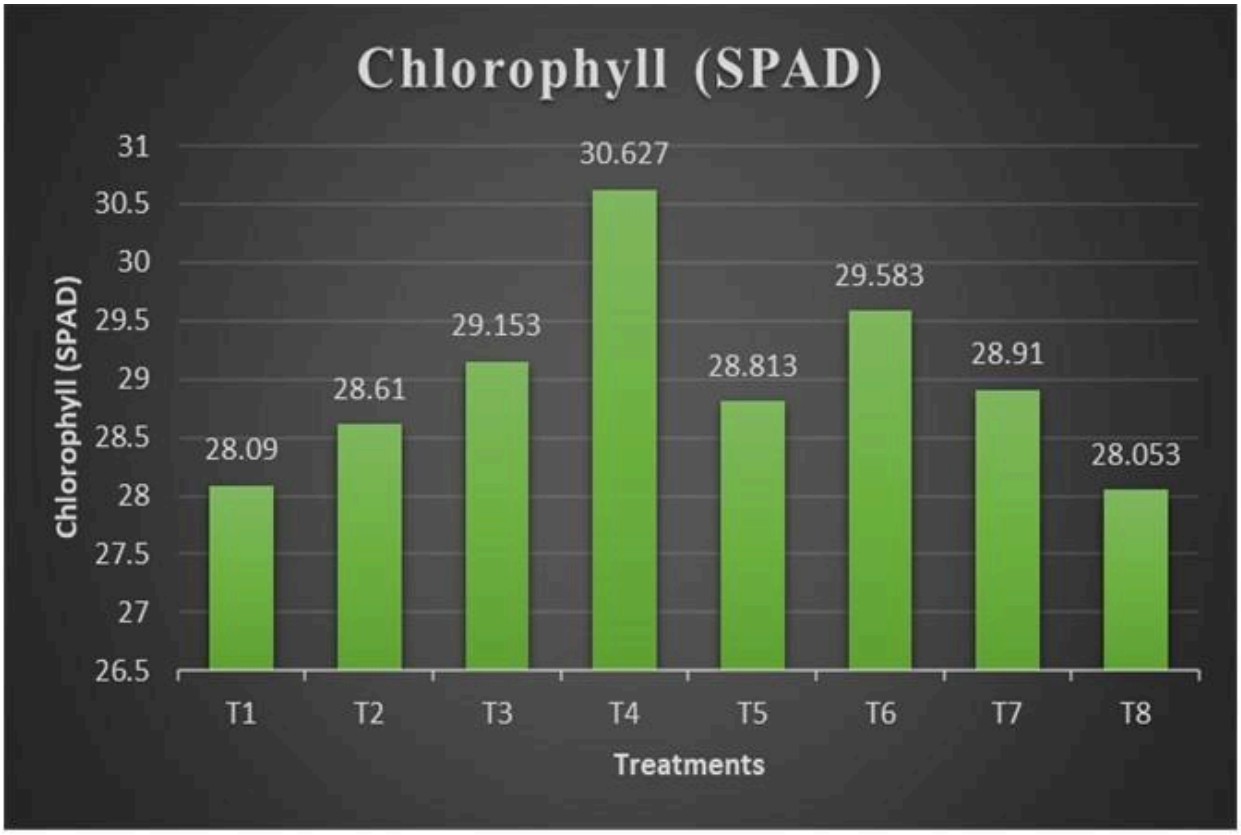


Fig. 5: Graph representing the difference in chlorophyll content of Coriander CO (CR) 4 at 40 DAS in different treatments

Table 2. Effect of bio-stimulants on Leaf area (cm^2) and Leaf Area Index (LAI) and chlorophyll content (SPAD)

Treatments	Leaf Area	Leaf Area Index	Chlorophyll (SPAD)
T1	36.413	0.120	28.090
T2	36.373	0.121	28.610
T3	40.080	0.134	29.153
T4	42.333	0.141	30.627
T5	40.530	0.135	28.813
T6	38.273	0.127	29.583
T7	37.473	0.124	28.910

T8	36.280	0.121	28.053
SE(d	**0.37**	**0.01**	**0.36**
CD @ 5%	**0.79**	**0.01**	**0.77**

Bio-stimulants have the greatest potential of increasing yield and production along with stress tolerance. Interpretation of the overall results revealed that Phytocil® had its significance in enhancing the growth and biochemical parameters when compared to others. Either individually or in combination, Phytocil® acts efficiently over CO (CR) 4 coriander production and quality. Silicon is one of the essential metals for the healthy growth of plants and has also been used as supplements over years for crops grown under saline condition (Hassanein *et al.*, 2022). Use of silicon nano-particles as nutrient supplement to enhance the growth and physiological characteristics under lead stress (Fatemi et al., 2017). Evidence showed that silica particles would help enhance the growth and yield by supporting the adoption of chemical and biological Si management strategies (Nath et al., 2026). As Phytocil has SiO_2 amorphous clay as a major ingredient, it would be the reason for the enhanced growth and herbage yield parameters. The effect of the bio-stimulant application process would also have a significant difference in the growth and yield (Kuneva et al., 2024). Use of bio-stimulant can increase saline tolerance along with enhanced growth (Al-Garni et al., 2019).

Effect of bio-stimulants on yield parameters

Among the 8 different treatments, T4 (Phytocil® + Humic acid) exhibited the highest root-fresh (1.19 g/plant) and dry (0.32 g/plant) biomass relative to its corresponding herbage yield. This indicates greater biomass allocation towards the root system. T8 (Control) showed relatively lower root dry biomass (0.17 g/plant), despite having an intermediate dry herbage yield (Table 5.). These comparative results suggested that it has very low below-ground dry matter. The overall plant biomass was found to be lower in T1 (Humic acid) and T2 (Seaweed extract), whereas higher in T3 (Phytocil®), T4 (Phytocil® + Humic acid) and T5 (Humic acid + Seaweed extract). As the shoot and root biomass were almost similar in terms of fresh weight, there exists a strong coordination between above- and below-ground growth under specific treatments.

Overall biomass allocation in Coriander CO (CR) 4 variety with the applied bio-stimulants indicates that it maintained coordinated root-shoot growth, with a slight

preferential increase in root biomass as plant biomass increased. The strong relationship between fresh and dry biomass explains the contribution of water use efficiency. The treatment-specific deviations from the regression line further indicate that the application of bio-stimulants may influence the biomass partitioning between shoot and root area. This provides an additional perspective for evaluating physiological effects between treatments beyond their growth and yield.

Table 3 Effect of bio-stimulants on herbage yield and root weight

Treatments	Fresh herbage yield (g/plant)	Dry herbage yield (g/plant)	Root fresh weight (g/plant)	Root dry weight (g/plant)
T1	26.82	5.47	0.84	0.20
T2	28.35	5.91	0.88	0.22
T3	33.64	7.18	1.06	0.24
T4	37.51	8.42	1.19	0.32
T5	35.09	7.65	1.12	0.24
T6	31.87	6.84	1.00	0.22
T7	30.24	6.42	0.94	0.21
T8	29.16	6.13	0.90	0.17
SEd	0.08	0.02	0.02	0.02
CD @ 5%	0.17	0.03	0.04	0.05

Allometric analysis of herbage and root yield

The relationship between root-shoot biomass was positive allometric in coriander CO (CR) 4 with increasing root biomass being slightly faster than shoot biomass on bio-stimulants application (Figure 6). For fresh biomass, the fitted power law relationship was $Y = 0.024X1.078$ with an allometric coefficient ($b = 1.078$) significantly greater than 1 ($p < 0.001$) and a very high coefficient of determination ($R^2 = 0.997$). This suggested a very strong and consistent positive correlation between fresh herbage yield and root fresh weight across treatments. The value of $b > 1$ indicates that shoot productivity increases were associated with a proportionally larger increase in root biomass, suggesting increased below-ground biomass allocation with increasing plant size.

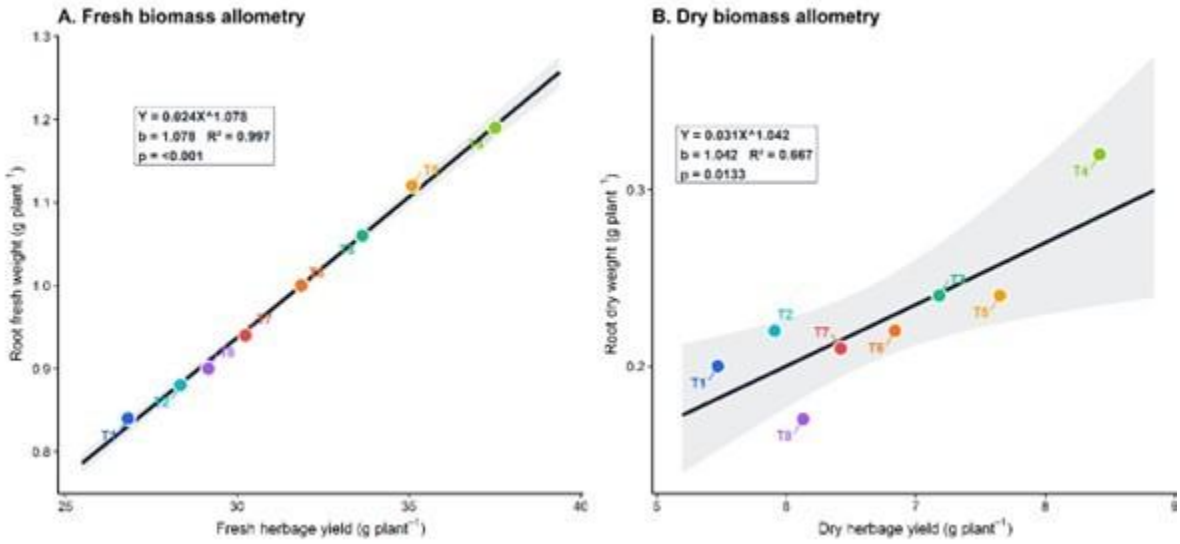


Fig. 6: Allometric analysis graph comparing fresh and dry biomass of Coriander CO (CR) 4 at 40 DAS in different treatments

The relationship of the dry biomass was positive allometric, Y = 0.031X1.042 (b = 1.042; p = 0.0133). The relationship was statistically significant, but had comparatively less explanatory power (R2 = 0.667) than that for fresh biomass. The value of b>1 indicates that root dry matter increased nearly proportionally, but rapidly, with increasing dry herbage yield. The lower R^2 indicates that dry matter partitioning has more variation associated with the treatments. This may be due to differences in absorbed water content, assimilate allocation or biomass accumulation among treatments.

CONCLUSION

It was evident from the experiments carried out using combinations of bio-stimulants as different treatments that the use of bio-stimulant will help in increasing the economic outcome of crops like coriander CO (CR) 4. In these 8 treatments, T4 (Phytocil® + Humic acid®) excelled in all the parameters showing the efficiency of bio-stimulants used in combination. Also, the bio-stimulant Phytocil® used as an individual in T3 had well-determined growth and yield enhancement. The use of bio-stimulants such as Phytocil®, Humic acid® and Seaweed extract could alter the actual physiological and biochemical cycles which will be the reason for the increased performance. As bio-stimulants are one of the promising futuristic crop growth enhancers, it will be environment-friendly and used in sustainable agriculture. Future studies

with different concentrations in various crops could increase the awareness of increased sustainable farming to the farming community.

Statements and declarations

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Competing interest

The authors declare that there are no competing interests to declare.

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