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Maximizing the productivity of green gram (*Vigna radiata* L.) by irrigation regimes and foliar application of biostimulants

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Abstract
A field experiment was conducted on clay soils at College Farm, SRM College of Agricultural Sciences, Baburayanpettai, during the summer of 2024 to evaluate maximizing the productivity of green gram by irrigation regimes and foliar application of biostimulants. The experiment was designed with a split-plot design and replicated three times. The study involved three primary irrigation levels in main plots, *viz.*, 50% ETc (M_1), 75% ETc (M_2), and 100% ETc (M_3), and irrigation was given at 10 days intervals based on crop evapotranspiration (ETc). Additionally, four biostimulant treatments were adopted in subplots, *viz.*, foliar spraying of 5 L $ha^{-1}$of plant-based biostimulant, namely Pepto (S_1), 2% seaweed extract (S_2), 2% humic acid (S_3), and 2% DAP (S_4), which were applied to 30 and 45 DAS. The experiment results revealed that among the irrigation treatments, 100% ETc (M_3) irrigation level significantly outperformed the other irrigation treatments in enhancing growth, physiological yield parameters, and nutrient uptake. In terms of irrigation of 100% ETc (M_3) and biostimulants, the application of 2% seaweed extract (S_2) twice, at 30 and 45 DAS, led to significantly increased growth and yield. This was closely followed by irrigation of 100% ETc (M3) and 2% humic acid (S3) treatment, which also showed substantial benefits compared to the other biostimulant treatments.

Keywords: Deficit irrigation, biostimulants, seaweed extract, growth and yield

Introduction
Pulses play a vital role in Indian agriculture since they actively contribute to the restoration of soil fertility. The process involves the utilization of Rhizobium bacteria within root nodules to fix atmospheric nitrogen, hence enhancing the soil's nutrient content. In addition, pulses possess the ability to withstand drought conditions, rendering them indispensable in places with limited water availability. Their broad root systems and substantial ground coverage serve to mitigate soil erosion, preserving the long-term health and viability of cultivable land. Green gram, also known as mung bean, is a nutritious legume native to India and Central Asia. It is a highly-grown pulse crop in India, contributing to 10% of overall pulse production and covering 16% of the total land. India and Myanmar collectively contribute 30% of global production. Rajasthan is the leading state in mung bean cultivation.

Green gram is cultivated and grown across India for its utilization as a vegetable, pulse, fodder, and green manure crop. Nevertheless, the cultivation of this crop frequently encounters challenges such as insufficient seed production and subpar development caused by inadequate management techniques and soil fertility problems. The loss of nitrogen through leaching, volatilization, and phosphorus fixation results in inadequate availability of these nutrients during crucial stages, which negatively impacts crop output.

Green gram productivity is declining due to inefficient sowing methods, soil insufficient moisture, and inadequate application of nutrients. Proper water management is crucial for green gram crops, especially during flowering and pod filling phases. Waterlogging and drought stress can negatively impact crop output, emphasizing the need for balanced nourishment and timely watering. Patel and Chauhan (2019) [18]. Deficit irrigation is a technique in which a crop is watered with an amount of water that is less than what is needed for maximum plant growth.

The main intention of this strategy is to reduce the amount of water used for crop irrigation and improve the plants response to a particular level of water scarcity, increasing the crop's water productivity (Chai *et al.*, 2016) [3].

Low nutrient fertility in green gram cultivation can be attributed to factors like fertilizer requirements, soil depletion, incorrect crop rotation, and insufficient fertilization methods, leading to reduced crop yields. (Yadav *et al.*, 2020) [21]. Foliar nutrition enhances crop production by applying nutrients directly to the leaves during critical growth periods, which promotes effective photosynthesis and balanced development. This method can increase crop yields by 15 to 25%, as plants utilize nearly 90% of foliar-applied fertilizers. Additionally, foliar applications of macro and micronutrients, along with growth regulators, are more efficient and cost-effective compared to soil applications, allowing for quick correction of nutrient deficiencies when needed. Applying biostimulants through foliar spray is crucial for facilitating direct nutrient uptake by leaves, leading to rapid improvements in plant growth, stress resilience, and overall crop productivity. This method enhances nutrient utilization during key growth stages and helps mitigate the effects of environmental stressors (Kumar *et al.*, 2021) [12].

Hence, this study aims to enhance the productivity of green gram by implementing deficit irrigation together with biostimulants and the prescribed dosage of fertilizer NPKS in a 25:20:25:20 ratio. The objective is to improve the growth and yield parameters of green gram.

Materials and Methods

In the present study, seeds of the VBN 5 variety were utilized for the experiment, which was conducted during the summer season of 2024 at SRM College of Agricultural Sciences, College Farm, Baburayanpettai, Tamil Nadu, India. The studies aimed to maximize green gram productivity by irrigation regimes and foliar application of biostimulants.

The soil at the experimental site was characterized as clay with a pH of 7.5, organic carbon content of 1.2%, and available nutrients of low-level nitrogen (138 kg ha^{-1}), low-level phosphorus (10 kg ha^{-1}), and medium-level potassium (120 kg ha^{-1}). To ensure optimal growth conditions, a recommended fertilizer dose of 25:50:25:20 (NPKS) kg ha^{-1} was uniformly applied to all experimental plots at the time of sowing as a basal application. The experimental design employed a split plot and was replicated thrice. The main plots were assigned to three levels of deficit irrigation: M_1 (50% ETc), M_2 (75% ETc), and M_3 (100% ETc). Within each main plot, four biostimulant treatments were applied as subplots: S_1 (5 L ha^{-1} of plant-based biostimulants, namely Pepto), S_2 (2% seaweed extract), S_3 (2% humic acid), and S_4 (2% DAP).

On the day of sowing, an initial irrigation was provided to ensure optimal seedbed conditions. This was followed by a critical life-saving irrigation three days post-sowing to support early seedling establishment. Subsequent irrigations were scheduled based on daily pan evaporation data under the prescribed treatment plan. The volume of irrigation water was precisely measured using a parshall flume, and the delivery time was meticulously recorded with a stopwatch to quantify the exact amount of water supplied to each plot.

Evaporation losses were monitored using an open pan evaporimeter, and the required volume of irrigation water was calculated by summing the crop evapotranspiration (ETc) values using the formula: $ETc=ETo \times Kc$

Where ETc represents crop evapotranspiration, ETo stands for reference evapotranspiration, and Kc is the Crop coefficient. The crop factor (Kc) values used for different growth stages were: initial stage (0.4), mid-stage (1.05), and late stage (0.35), reflecting the varying water needs of the green gram throughout its development. Foliar application of various biostimulants at 30 DAS and 45 DAS with the help of a knapsack sprayer.

The experimental plots were sized at 5 m × 4 m (20.0 m^2) and 30 cm × 10 cm spacing adopted to maintain the optimum plant population. Five randomly tagged plants served as the representative population in each net plot, recording their biometric observations of the plants included measurements of plant height (cm), the number of branches $plant^{-1}$, the leaf area index, the production of dry matter, and yield parameters like a number of pods $plant^{-1}$, the number of seeds pod^{-1}, the seed yield, and the haulm yield. The data recorded were statistically analyzed for split design using the Analysis of Variance (ANOVA) at a 5% level of significance using R Studio version 4.2.2. The Treatment differences that were non- significant were denoted by "NS".

Results and Discussion

Plant height (cm)

The growth plant height of Greengram was found to be non-significant regarding irrigation levels and nutrition treatments. The highest plant height was recorded with irrigation at 100% ETc (60.84 cm) (Table 1). This could be due to improvement in soil available moisture in the root zone through irrigation enhanced growth of the plant leading to more plant height. A similar obvious result was also observed by (Mondal *et al.* (2018) [15]. The influence of biostimulants on the plant height of green gram was also found to be non-significant at all the growth stages of the crop. The highest plant height at harvest (56.72 cm was recorded with a foliar spray of 2% seaweed extract) (Table 1). Due to the presence of auxin in seaweed extract, which has been shown to significantly contribute to cell growth and enlargement (Dilavarnaik *et al.*, 2017) [4]. Similarly, the increase in plant height and the beneficial impact of seaweed extract liquid fertilizers on plant health can be attributed to its encouraging effects on growth and development. When considering the influence of this fertilizer on crops, it is essential to examine factors such as root development, mineral absorption, shoot growth, and the photosynthetic processes within the plant system. These findings are in agreement with those of Pramanick *et al.* (2016) [19]. The interaction between deficit irrigation at 100% ETc and foliar spray of 2% seaweed extract was found to be non-significance in plant height of greengram.

Number of branches $plant^{-1}$

The influence of irrigation and biostimulants on a number of branches of $plant^{-1}$ was found to be non-significant at harvest. The highest number of branches $plant^{-1}$(1.68) (Table 1). Recorded irrigation at 100% ETc At the harvest stages. This was because gets good establishment of roots was due to the strong depurate moisture supply in the soil, which performed higher nutrient mobilization and uptake. (Sodavadiya *et al*., 2017) [25] reported that due to the availability of optimum moisture contributed to the effective absorption and utilization of nutrients and better proliferation of roots resulting in better primary and secondary branches per plant. The influence of biostimulants was also found to be non-significant, with the highest number of branches in $plant^{-1}$ (1.41) (Table 2). Was recorded with a foliar spray of 2% seaweed extract. Applying seaweed extracts has enhanced the overall growth compared to control plants. An increase in plant height and number of

branches per plant has been reported in different crops by using seaweed extract (Kumar and Sahoo, 2011; Dwivedi *et al.*, 2014) [11, 5]. The interaction between deficit irrigation at 100% ETc and foliar spray of 2% seaweed extract was found to be non-significance in the number of branches of green gram.

Table 1: Maximizing the productivity of green gram by irrigation regimes and foliar application of biostimulants on plant height and number of branches plant at harvest stage of green gram (summer 2024)

Treatment	Plant height (cm)					Number of branches plant^{-1}				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
M_1	51.05	49.41	49.53	47.99	49.49	1.01	1.02	1.06	1.01	1.03
M_2	50.19	57.83	51.89	53.04	53.24	1.26	1.51	1.49	1.48	1.43
M_3	60.95	62.93	63.97	55.52	60.84	1.70	1.71	1.66	1.65	1.68
Mean	54.06	56.72	55.13	52.18		1.33	1.41	1.40	1.38	
	M	S	M at S	S at M		M	S	M at S	S at M	
SE(d)	1.20	1.32	2.64	2.58		0.03	0.03	0.07	0.07	
CD ($p \leq 0.05$)	2.93	2.73	NS	NS		0.07	0.07	NS	NS	

Main plots (M) - Irrigation levels	Subplots (S) - Foliar spray of Biostimulants
M_1 : Irrigation @ 50% ETc	S_1 : Bio-stimulant @ 5 L/ha on 30 and 45 DAS
M_2 : Irrigation @ 75% ETc	S_2 : Sea Weed extract @ 2% on 30 and 45 DAS
M_3 : Irrigation @ 100% ETc	S_3 : Humic acid @ 2% on 30 and 45 DAS
	S_4 : DAP @ 2% on 30 and 45 DAS

Leaf area index (LAI)

The leaf area index of Greengram was found to be significant regarding irrigation levels and biostimulant treatments. The highest value was recorded with irrigation at 100% ETc (2.52) (Table 2). This could be enhanced vegetative growth discoveries in an extensive photosynthesis system and a relative increase was recorded in leaf area index. Similarly, the same results were concluded by Megharani *et al.* (2020) [14]. The influence of biostimulants was significant; the highest leaf area index value (2.36) was recorded with a foliar spray of 2% seaweed extract. The positive effects of seaweed extract might be due to the existence of some growth-stimulating substances (IAA, IBA, Gibberellins, Cytokinins, micronutrients, and amino acids). This statement, to the findings of Rao *et al.* (2015) [20]. The interaction effect of deficit irrigation at 100% ETc along with a foliar spray of 2% seaweed extract recorded the highest value (2.74) and was found to be significant at the harvest stage. Adequate irrigation combined with seaweed extract application promotes robust leaf growth, resulting in a higher LAI, which boosts photosynthetic capacity (Zhang *et al.*, 2019) [23]. Similarly, under deficit irrigation, seaweed extracts can mitigate stress effects, helping maintain LAI and overall plant vigor (Khan *et al.*, 2020) [10]. Thus, integrating both factors can enhance crop productivity and sustainability.

Dry matter production

The dry matter production at different growth stages clearly showed a gradual increase as the crop matured. At the harvest stage of crop growth, the highest dry matter production g was recorded at 100% ETc (16.50 g plant^{-1}) (Table 2). Which was significantly superior to all other irrigation treatments. It may attributed an increased plant height and leaf area discoveries in higher dry matter accumulation, which was due to the maintenance of favourable soil water balance across the crop life (Megharani *et al.*, 2020) [14]. The influence of biostimulants on dry matter production of green gram was found to be significant at all the growth stages of the crop. Foliar spraying of 2% seaweed extract recorded the highest dry matter production (14.43 g plant^{-1}) (Table 2). At harvest stage, foliar spray with 2% seaweed extract was comparable with 2% DAP. Seaweed Liquid Fertilizers (SLF) contain a wide range of micro- and macronutrients, trace elements, amino acids, plant growth-promoting hormones, vitamins, antibiotics, carbohydrates, proteins, and other organic matter. These substances have qualities that stimulate plant development when used in diluted form. These results are confirmed with Moshe *et al*. (2015) [16]. The interaction effect of deficit irrigation levels and biostimulants on dry matter production was found to be significant at all stages of crop growth and the highest value (17.02) was reordered the application of 2% seaweed extract significantly enhances various growth and developmental processes in plants, promoting their overall health and vitality. This could be Increased irrigation coupled with optimal seaweed extract application promotes nutrient uptake and improves soil moisture, leading to robust plant growth and exhibit higher biomass compared to those receiving either treatment alone. These findings are in agreement with (El-Abd *et al.*, 2016) [6]

Table 2: Maximizing the productivity of green gram by irrigation regimes and foliar application of biostimulants on Leaf area index and dry matter production plant at harvest stage of green gram (Summer 2024)

Treatment	Leaf area index					Dry matter production (g ha^{-1})				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
M_1	1.83	2.02	1.79	1.57	1.80	9.75	11.19	11.08	8.86	10.22
M_2	2.07	2.33	2.03	2.09	2.13	12.75	15.07	12.84	11.47	13.03
M_3	2.28	2.74	2.58	2.47	2.52	17.02	17.02	17.17	14.78	16.50
Mean	2.06	2.36	2.13	2.04		13.17	14.43	13.70	11.70	
	M	S	M at S	S at M		M	S	M at S	S at M	
SE(d)	0.03	0.05	0.09	0.09		0.19	0.27	0.55	0.51	
CD ($p \leq 0.05$)	0.07	0.10	0.18	0.14		0.46	0.57	1.06	0.85	

Main plots (M) - Irrigation levels	Subplots (S) - Foliar spray of Biostimulants
M_1 : Irrigation @ 50% ETc	S_1 : Bio-stimulant @ 5 L/ha on 30 and 45 DAS
M_2 : Irrigation @ 75% ETc	S_2 : Sea Weed extract @ 2% on 30 and 45 DAS
M_3 : Irrigation @ 100% ETc	S_3 : Humic acid @ 2% on 30 and 45 DAS
	S_4 : DAP @ 2% on 30 and 45 DAS

Yield and haulm yield (kg ha^{-1})

The seed yield and Haulm yield are important yield components that are influenced by agronomic crop management and the environment.

The seed yield and haulm yield were significantly affected by the different irrigation levels based on crop evapotranspiration (Table 5). The highest seed yield (753 kg ha-1) and haulm yield (1838 kg ha-1) was recorded for irrigation at 100% ETc (M3). The lowest yield was seen with 50% ETc irrigation, which yielded 445.01 kg ha^{-1}. This could be due to maintaining optimal soil moisture conditions and the availability of various nutrients. Moreover, consistent moisture availability at all stages of crop growth and development contributed to higher water potential, improved stomatal conductance, enhanced photosynthesis, and more efficient partitioning of photosynthates to sinks, ultimately leading to increasing seed yield. The same results were the findings of Sodavadiya *et al.* (2017[25]). Among the different foliar treatments, the highest seed yield (655 kg ha^{-1}) and haulm yield (1627 kg ha-1) were recorded by applying foliar spraying of 2% seaweed extract (S2). This could be due to the presence of micro and macro elements and biostimulants, especially cytokinins, which increased yield. The same was obvious through the findings of Zodape *et al.* (2010) [24], and Ganapathy *et al.* (2013) [7]. The potential reason for the enhanced haulm yield could be attributed to the consistent provision of nutrients, which may have led to an expansion in leaf area and dry matter, thereby resulting in a greater haulm yield (Kuttimani and Velayutham, 2011) [13]. The interaction between deficit irrigation and biostimulants shows a significant difference in seed yield (813 kg ha^{-1}) and haulm yield (1947 kg ha^{-1}) was recorded by applying irrigation at 100% ETc along with 2% seaweed extract. It was due to optimal moisture and seaweed extract combinations that promote better root development and the ability to utilize the available moisture as well as various nutrients, leading to improved overall productivity even under water-limited conditions. The interaction between deficit irrigation and seaweed extract application significantly influences both yield and haulm yield in Greengram. This combination promotes better root development and enhances the plant's ability to utilize available moisture, leading to improved overall productivity even under water-limited conditions. The same results were obvious through the findings (Zodape *et al.*, 2010) [24].

Yield attributes

The data on yield attributes demonstrated that both deficit irrigation and biostimulant treatments had a significant impact. Notable differences were observed in key yield attributes, including the number of pods per plant, the number of seeds per pod, pod length, and test weight. (Table 3, 4).

The irrigation treatment with 100% ETc resulted in the highest values for yield attributes, including the number of pods per plant (44.25), number of seeds per pod (11.29), pod length (7.23 cm), and test weight (3.64 g). This treatment was significantly better than all other irrigation treatments. This could be attributed to maintaining optimal soil moisture conditions, which influenced root nodulation and the availability of various nutrients. Additionally, sufficient moisture throughout all stages of crop growth and development resulted in higher water potential, improved stomatal conductance, enhanced photosynthesis, and better allocation of photosynthesis to sinks, ultimately leading to an increase in the yield attributes. These results also were found with Megharani *et al.* (2020) [14] and Muniyappa *et al.* (2017) [17]. Among the biostimulants, a 2% seaweed extract resulted in the highest values for yield parameters, including the number of pods per plant^{-1} (36.39.), seeds per pod^{-1} (11.17), pod length (7.29 cm), and test weight (3.51 g). The positive impacts of seaweed extract may stem from the existence of growth-stimulating chemicals such as IAA, IBA, Gibberellins, Cytokinins, minerals, and amino acids. A similar conclusion was evident from the discoveries made by Rao *et al.* (2015) [20]. The interaction between irrigation at 100% (M_3) and foliar spraying of 2% seaweed extract (S_2) resulted number of pods per plant^{-1} (48.83.39.), seeds per pod^{-1} (11.51), pod length (7.85 cm), and test weight (3.63 g) was significantly superior over the remaining other treatments. This could be Deficit irrigation, when supplemented with seaweed extract, enhances water-use efficiency and nutrient absorption, leading to improved reproductive traits despite limited water availability same results were found with (Jafaar *et al.*, 2023) [9]

Table 3: Maximizing the productivity of green gram by irrigation regimes and foliar application of biostimulants on Number of pods plant^{-1} and Number of seeds pod^{-1} of green gram (summer 2024)

Treatment	Number of pods plant^{-1}					Number of seeds pod^{-1}				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
M_1	19.33	21.50	22.00	20.50	20.83	10.23	10.73	10.70	10.17	10.46
M_2	36.00	38.83	37.17	33.17	36.29	11.15	11.27	11.13	10.83	11.10
M_3	42.17	48.83	45.33	40.67	44.25	11.17	11.51	11.33	11.13	11.29
Mean	32.50	36.39	34.83	31.44		10.85	11.17	11.06	10.71	
	M	S	M at S	S at M		M	S	M at S	S at M	
SE(d)	0.91	0.60	1.19	1.38		0.16	0.14	0.28	0.29	
CD (p≤0.05)	2.23	1.23	2.84	1.85		0.38	0.29	0.59	0.43	

Table 4: Maximizing the productivity of green gram by irrigation regimes and foliar application of biostimulants on pod length (cm) test weight of green gram (summer 2024)

Treatment	Pod length (cm)					Test weight (g)				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
M_1	6.72	7.11	7.11	6.18	6.78	3.42	3.31	3.55	2.88	3.29
M_2	7.05	6.92	7.02	7.08	7.02	3.59	3.58	3.59	3.53	3.57
M_3	7.01	7.85	7.04	7.01	7.23	3.65	3.63	3.67	3.63	3.64
Mean	6.93	7.29	7.06	6.76		3.55	3.51	3.60	3.34	
	M	S	M at S	S at M		M	S	M at S	S at M	
SE(d)	0.12	0.11	0.23	0.23		0.08	0.07	0.14	0.14	
CD (p≤0.05)	0.29	0.24	0.48	0.35		0.19	0.14	0.29	0.21	

Table 5: Maximizing the productivity of green gram by irrigation regimes and foliar application of biostimulants on Seed yield kg ha^{-1} and Haulm yield kg/ha^{-1} of green gram (summer 2024)

Treatment	Seed yield kg ha^{-1}					Haulm yield kg ha^{-1}				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
M_1	443	473	447	417	445	917	1266	1067	800	1012
M_2	537	680	633	494	586	1500	1665	1551	1351	1517
M_3	732	813	757	712	753	1851	1949	1900	1652	1838
Mean	571	655	612	541		1423	1627	1506	1267	
	M	S	M at S	S at M		M	S	M at S	S at M	
SE(d)	11	14	29	27		29	23	46	49	
CD (p≤0.05)	28	30	56	44		70	48	102	72	

Main plots (M) - Irrigation levels	Subplots (S) - Foliar spray of Biostimulants
M_1 : Irrigation @ 50% ETc	S_1 : Bio-stimulant @ 5 L/ha on 30 and 45 DAS
M_2 : Irrigation @ 75% ETc	S_2 : Sea Weed extract @ 2% on 30 and 45 DAS
M_3 : Irrigation @ 100% ETc	S_3 : Humic acid @ 2% on 30 and 45 DAS
	S_4 : DAP @ 2% on 30 and 45 DAS

Conclusion

The study effectively demonstrates that applying 100% ETc irrigation consistently results in better growth, and yield of green gram compared to lower irrigation levels. Among the biostimulants evaluated, a 2% seaweed extract was the most effective at increasing plant height, dry matter, and seed yield, particularly when used with full irrigation, achieving a maximum seed yield percentage 59% for ha^{-1}. While deficit irrigation (75% and 50% ETc) can lower water usage, it adversely affects crop yield and growth unless paired with effective biostimulants. The research emphasizes the importance of combining 100% ETc irrigation with biostimulants to optimize productivity and provide valuable insights for farmers to improve crop performance and resource conservation. Future studies should explore the long-term impacts of these methods on soil health, their cost-effectiveness, and their relevance to other crops.

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