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INFLUENCE OF NAA, BORON AND MOLYBDENUM ON GROWTH AND PHYSIOLOGY OF GREEN GRAM (*VIGNA RADIATA* WILCZEK) IN SUBTROPICAL REGIONS

Samrat S. Dhadge[1,2], Amol P. Solanke[1,2,4]*, Shashianand U. Kalbhor[3,4], B. J. Gawhale[4] and S.S. Shinde[1]

[1]Department of Agricultural Botany, College of Agriculture, V.N.M.K.V., Parbhani - 431 402 (M.S), India.
[2]Department of Agricultural Botany, PGI, MPKV, Rahuri, Ahmednagar - 413 722 (M.S), India.
[3]Department of Entomology, Dr. SPCOA, Baramati - 413 115 (M.S.), India.
[4]ICAR- National institute of abiotic stress management, Malegaon, Baramati - 413 115 (M.S.), India.
*Corresponding author E-mail : amol.solanke20@gmail.com

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ABSTRACT

The present investigation was conducted during the June - Aug 2017 at the experimental field, Department of Agricultural Botany, VNMKV, Parbhani utilized a randomized block design with three replications in BM-2002-01 green gram variety in black cotton soil to "study the effect of NAA, boron and molybdenum on growth and physiology of green gram (*Vigna radiata* Wilczek)" with combination of T_0 (Control), T_1 (NAA 40 ppm), T_2 (Boron 0.2%), T_3 (Molybdenum 0.05%), T_4 (NAA 40 ppm + Boron 0.2%), T_5 (NAA 40 ppm + Molybdenum 0.05%), T_6 (Boron 0.2% + Molybdenum 0.05%) and T_7 (NAA 40 ppm + Boron 0.2% + Molybdenum 0.05%). According to the study, there were statistically significant differences between the treatments and control conditions for plant height, number of branches, functional leaves, mean leaf area per plant and dry matter accumulation when treatment T_7 (foliar application of NAA 40 ppm + boron 0.2% and molybdenum at 0.05%) was used. Furthermore, compared to the other treatment, T_7 treatments elevated the growth parameter. The results of this study suggest that NAA, boron and molybdenum together can be used to increase green gram productivity in subtropical areas.

Key words : Green gram, NAA, Boron, Molybdenum, Growth, Subtropical Regions.

Introduction

Mungbean (*Vigna radiata* Wilczek) is a leguminous crop commonly referred to as green gram, has been cultivated for centuries across various regions, particularly in southern and eastern Asia (Bankar *et al*., 2020; Meena *et al*., 2020). It is considered one of the most ancient and extensively grown legume crops in India (Pathak *et al*., 2021), occupying approximately 3.4 Mha and contributing to 1.4 MT of pulse production within the country (Choudhary *et al*., 2017).

Mungbean is highly valued for its nutritional profile containing around 25% protein, which is nearly 3 times higher than that of cereals, making it a staple food for the vegetarian population of India. India is the world's largest producer of green gram, accounting for 65% of the global acreage and 54% of the total production. The low productivity of green gram in India, which averages around 425 kg h^{-1} (Pathak *et al*., 2021) can be attributed to various factors, including nutritional deficiencies in the soil and imbalanced external fertilization (Choudhary *et al*., 2017).

Micronutrients, such as boron and molybdenum, play a crucial role in the growth and development of green gram plants (Swamygowda *et al*., 2020). Boron is essential for the formation of reproductive structures, pollen germination and seed development, while molybdenum is involved in nitrogen fixation and the activation of various enzymes (Kumar *et al*., 2020). Furthermore, the application of plant growth regulators, such as naphthalene acetic acid, has been shown to have a positive impact on the seed yield and vigor of green gram (Pathak *et al*., 2021). Enhancing the productivity and nutritional quality of green gram through balanced fertilization including the application of micronutrients and plant growth regulators is crucial for improving the crop's performance and contributing to India's food security.

The objective of this study is to investigate the influence of naphthalene acetic acid, boron and molybdenum on the growth and physiology of green gram cultivated in the subtropical regions of India.

Materials and Methods

Experimental Design and Site Description

This study was conducted during the Kharif season of 2017-18 at the Experimental Field, Department of Agricultural Botany, Vasantrao Naik Marathwada Agricultural University, Parbhani - 431 402, Maharashtra, India. The field, characterized by medium black soil, is located at 19°16' North latitude and 76°47' East longitude and experiences a subtropical climate with an average annual rainfall of 402.8 mm over 35 rainy days. The experiment was conducted under rainfed conditions.

Treatments and Crop Management

A Randomized Block Design with three replications was employed. The green gram variety BM-2002-01 was sown on 27^{th}June, 2017 using the dibbling method at a spacing of 45 x 10 cm. A fertilizer dose of 25:50:50 N, P and K kg ha^{-1} was applied with half the nitrogen and full doses of phosphorus and potassium administered at sowing.

Eight treatments were evaluated

T_0 (Control), T_1 (NAA 40 ppm), T_2 (Boron 0.2%), T_3 (Molybdenum 0.05%), T_4 (NAA 40 ppm + Boron 0.2%), T_5 (NAA 40 ppm + Molybdenum 0.05%), T_6 (Boron 0.2% + Molybdenum 0.05%) and T_7 (NAA 40 ppm + Boron 0.2% + Molybdenum 0.05%).

Micronutrients (boron and molybdenum) and the growth regulator were applied through foliar spraying at the flower initiation stage. Standard crop management practices, including gap filling, thinning, two hand weeding sessions, one hoeing and monocrotophos spraying (10%) for pest control were followed. Irrigation was dependent on rainfall.

Data Collection and analysis

Biometric observations including plant height, number of branches, number of leaves per plant and leaf area were recorded every 15 days from 15 days after sowing until 60 days. Dry matter accumulation was assessed at the same intervals by harvesting five plants randomly from each plot. The harvested plants were separated into leaves, stems and pods, oven-dried at 80°C for 48 hours and weighed. Growth analysis was conducted to determine Absolute Growth Rate, Relative Growth Rate, Net Assimilation Rate, Crop Growth Rate and Leaf Area Index.

Absolute Growth Rate (AGR)

AGR is the rate of increase of growth variable (W) and the time (t). It is measured as the differential coefficient of W with respect to time (t). It is expressed in g day^{-1}. It was calculated by using formula given by Richards (1969).

$$\text{AGR for dry matter} = \frac{W_2 - W_1}{T_2 - T_1}$$

Where,

W_2 and W_1 refer to dry matter weight per plant at T_2 and T_1 time, respectively.

Relative Growth Rate (RGR)

RGR quantifies the rate at which plants incorporate new material into their biomass. It is calculated using Fisher's formula (1921) to evaluate the relative rate of dry matter accumulation in plants over time. It is expressed in (g^{-1} day^{-1})

$$\text{RGR} = \frac{\text{loge}W_2 - \text{loge}W_1}{T_2 - T_1}$$

Where,

$\log_e$ = Natural logarithm to the base (e = 2.3026), W_1 and W_2 weight of dry matter at time T_1 & T_2 respectively, T_1 & T_2 refers initial & final time of observation.

Net Assimilation Rate (NAR)

Net assimilation rate is expressed as increase in dry matter per unit leaf area per unit time. It is expressed in g dm^{-2} day^{-1}. The concept of NAR on the basis of leaf area was introduced by Gregory (1982).

$$\text{NAR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\text{loge } A_2 - \text{loge } A_1}{A_2 - A_1}$$

Where,

W_1 and W_2 refers weight of dry matter at time T_1 & T_2 respectively, T_1 & T_2 refers initial & final time of observation as well as A_1 and A_2 refers leaf area per plant at time T_1 & T_2, respectively.

Crop Growth Rate (CGR)

The method was suggested by Watson (1952). The CGR explains the dry matter accumulated per unit land area per unit time (g m^{-2} day^{-1}).

$$CGR = \frac{(W_2 - W_1)}{\rho\ (t_2 - t_1)}$$

Where,

W_1 and W_2 are whole plant dry weight at time $t_1 - t_2$ respectively, ρ is the ground area on which W_1 and W_2 are recorded.

Leaf Area index (LAI)

Watson (1952) proposed the concept of Leaf Area Index (LAI), which represents the ratio of leaf area to ground area occupied by a crop plant. LAI is calculated using a specific formula to quantify the extent of leaf coverage relative to the land area.

$$LAI = \frac{\text{Leaf area plant}^{-1}}{\text{Ground area plant}^{-1}}$$

Statistical analysis

The collected data were subjected to Fisher's method of analysis of variance to assess the significance of treatment effects. The statistical procedures followed the approach outlined by Panse and Sukhatme (1985). Significance levels were set at $P = 0.05$ for both 'F' and 't' tests. Critical difference values were calculated at the 5% level of significance, where the 'F' test indicated significant differences.

Results and Discussion

Vegetative growth

This study investigated the influence of NAA, boron and molybdenum on the vegetative growth of green gram. The results demonstrate that the application of these micronutrients, both individually and in combination with NAA, significantly enhanced various growth parameters compared to the control treatment.

Plant height

Significant variations in plant height were noted across the treatments at all growth phases with the control treatment exhibiting the largest variations as seen in Table 1 and Fig. 1. Evenwhile, NAA and micronutrient treatments all increased plant height, this impact wasn't statistically significant until 30 days after seeding. All stages of the plants were consistently tallest when T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%) was combined.

This finding aligns with previous research demonstrating the positive impact of NAA on plant height in various crops. For instance, NAA application has been

Table 1 : Comparative Impact of NAA, Boron, Molybdenum and their combination on key growth metrics in green gram.

Treatments	Plant height (cm)				Number of branches per plant				Leaf area per plant (dm^2)				Total dry weight per plant (g)				Number of Functional Leaves $plant^{-1}$			
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS
T_0	21.12	37.56	43.21	43.85	1.92	1.97	4.03	4.2	2.1	3.35	6.29	4.78	2.1	6.76	17.42	26.12	4.38	13.16	16.22	14.78
T_1	21.48	37.58	45.68	45.81	1.90	1.95	4.07	4.28	2.37	3.65	6.91	5.15	2.24	6.82	20.27	27.92	4.76	12	17.26	15.14
T_2	20.84	37.76	45.97	46.16	1.87	1.96	4.11	4.34	2.68	3.52	7.35	5.27	2.18	6.97	22.96	28.23	5.22	12.52	17.59	15.32
T_3	21.97	38.14	46.84	47.05	1.90	1.96	4.17	4.46	2.43	3.73	7.94	5.42	2.42	7.22	25.76	29.26	5.79	13.27	18.02	15.77
T_4	21.75	37.84	46.31	46.42	1.92	1.98	4.14	4.4	2.76	3.89	7.77	5.34	2.37	7.09	24.08	28.79	5.66	12.74	17.84	15.54
T_5	21.36	37.82	47.16	47.33	1.96	2.01	4.21	4.51	2.82	4.2	8.27	5.54	2.71	7.61	26.43	30.97	6.45	13.5	18.28	15.98
T_6	20.96	37.96	48.09	48.28	2.00	2.24	4.26	4.66	2.96	4.05	8.64	5.76	2.85	7.68	27.28	31.88	6.64	14.17	18.92	16.22
T_7	21.62	38.07	48.72	48.81	1.98	2.09	4.31	4.72	3.04	4.28	8.79	5.83	2.79	7.74	27.8	36.56	6.83	13.8	19.56	16.43
S.E.±	**0.46**	**2.43**	**0.73**	**0.63**	**0.19**	**0.10**	**0.04**	**0.08**	**0.22**	**0.25**	**0.17**	**0.11**	**0.40**	**0.32**	**0.53**	**1.92**	**0.96**	**0.43**	**0.49**	**0.20**
C.D.	**N.S.**	**N.S.**	**2.2**	**1.9**	**N.S.**	**N.S.**	**0.12**	**0.25**	**N.S.**	**N.S.**	**0.52**	**0.34**	**N.S.**	**N.S.**	**1.6**	**5.8**	**N.S.**	**N.S.**	**1.5**	**0.6**
Mean	**21.39**	**37.84**	**46.5**	**46.71**	**1.93**	**2.02**	**4.16**	**4.45**	**2.65**	**3.83**	**7.75**	**5.39**	**2.46**	**7.24**	**24**	**29.97**	**5.72**	**13.15**	**17.96**	**15.65**

Note: T_0 (Control), T_1 (NAA 40 ppm), T_2 (Boron 0.2%), T_3 (Molybdenum 0.05%), T_4 (NAA 40 ppm + Boron 0.2%), T_5 (NAA 40 ppm + Molybdenum 0.05%), T_6 (Boron 0.2% + Molybdenum 0.05%), T_7 (NAA 40 ppm + Boron 0.2% + Molybdenum 0.05%.

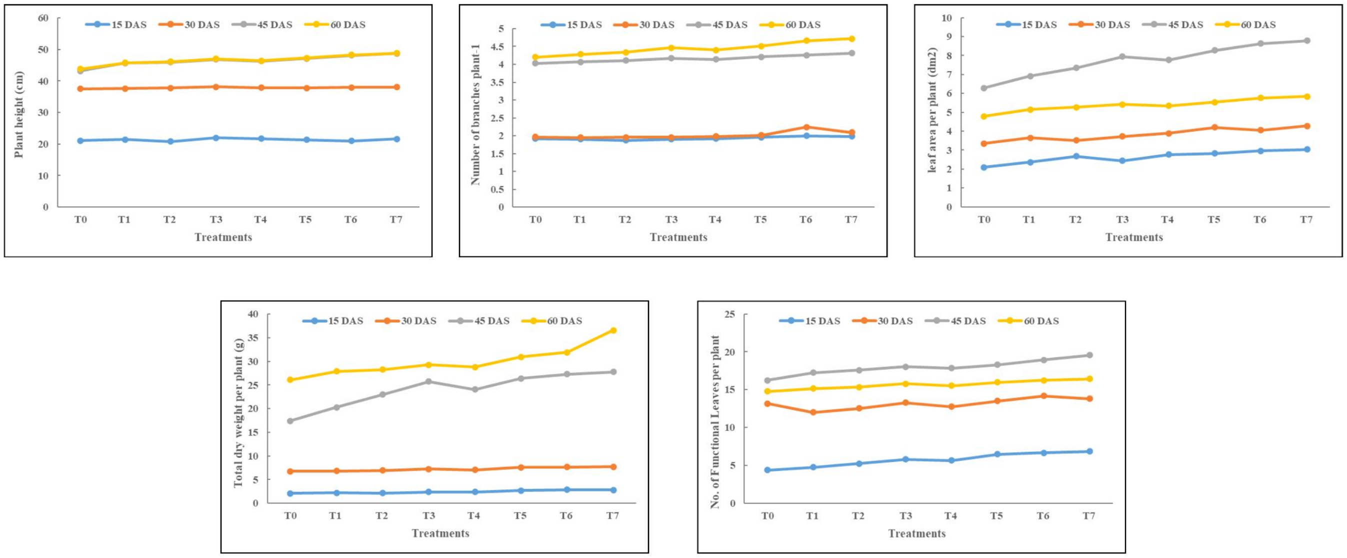

Fig. 1 : Comparative impact of NAA, Boron, Molybdenum and their combination on key growth metrics in green gram. **Note:** T_0 (Control), T_1 (NAA 40 ppm), T_2 (Boron 0.2%), T_3 (Molybdenum 0.05%), T_4 (NAA 40 ppm + Boron 0.2%), T_5 (NAA 40 ppm + Molybdenum 0.05%), T_6 (Boron 0.2% + Molybdenum 0.05%), T_7 (NAA 40 ppm + Boron 0.2% + Molybdenum 0.05%).

shown to increase plant height in mungbean and other legumes like lentil (Parveen *et al*., 2023). The enhanced plant height observed in T_7 could be attributed to NAA's role in promoting cell elongation and division in plant stems. This aligns with the findings of Boeuf *et al*. (2001), who reported that NAA application enhanced cell division and elongation in the stems of mungbean, leading to increased plant height.

Branches

The number of branches per plant were greatly altered, as Table 1 and Fig. 1 illustrate. When compared to the control, all treatments - especially T_7, T_6 and T_5 showed a considerable increase in branching. This research suggests that micronutrients and NAA work in concert to promote branching. In green gram, increased branching is a desirable characteristic because it can sustain more pods per plant which can increase production.

This increased branching can be attributed to the role of NAA and micronutrients in promoting cell division and lateral bud development, as highlighted by recent studies on various legume crops (Basile *et al*., 2020).

Functional leaves and mean leaf area per plant

Similar patterns were noted for the mean leaf area per plant and the number of functional leaves, as indicated in Table 1 and Fig. 1. The treatment with the greatest number of leaves and area was T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%), closely followed by T_6 and T_5. Because they promote cell division and expansion in leaf tissues, NAA and micronutrients have a positive influence on leaf growth. In order to absorb light energy, which directly affects photosynthesis and ultimately leads to increased biomass production, a bigger leaf area is essential.

This is consistent with findings in various crops, such as the effects of NAA on chicory root explants (Boeuf *et al*., 2001) and the influence of NAA and N-fertilizer on wheat (Adam *et al*, 2022).

Dry Matter Accumulation

The improved vegetative growth observed in treatments treated with NAA and micronutrients translated into much greater dry matter accumulation, as Table 1 and Fig. 1 illustrate. Over the period of the therapy, treatment T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%) outperformed all other treatments and achieved the greatest total dry weight.

This enhanced dry matter accumulation can be attributed to the positive effects of NAA and micronutrients on photosynthetic rate and nutrient uptake, as highlighted by Ramesh and Ramprasad (2014).

Growth Parameters

In addition to the assessment of direct vegetative traits, key growth parameters were calculated to provide a comprehensive understanding of NAA, boron and molybdenum influence on green gram growth dynamics. These parameters included Absolute Growth Rate, Relative Growth Rate, Net Assimilation Rate, Crop Growth Rate and Leaf Area Index.

Table 2 : Comparative impact of NAA, Boron, Molybdenum and their combination on comprehensive growth analysis of plant traits in green gram.

Treatments	Mean absolute growth rate (AGR)			Mean relative growth rate (RGR)			Mean Net Assimilation Rate			Mean Crop growth rate			Mean leaf area index			
	15-30 DAS	30-45 DAS	45-60 DAS	15-30 DAS	30-45 DAS	45-60 DAS	15-30 DAS	30-45 DAS	45-60 DAS	15-30 DAS	30-45 DAS	45-60 DAS	15 DAS	30 DAS	45 DAS	60 DAS
T_0	0.305	0.711	0.233	0.066	0.063	0.008	0.091	0.152	0.042	6.79	15.79	5.79	0.47	0.74	1.40	1.06
T_1	0.311	0.897	0.307	0.074	0.073	0.011	0..93	0.176	0.043	6.99	19.93	6.35	0.53	0.81	1.54	1.14
T_2	0.319	1.066	0.351	0.068	0.079	0.014	0.093	0.205	0.044	6.90	23.69	6.73	0.60	0.78	1.63	1.17
T_3	0.320	1.236	0.510	0.073	0.083	0.012	0.105	0.209	0.056	7.11	27.47	7.81	0.61	0.86	1.76	1.20
T_4	0.315	1.133	0.314	0.069	0.082	0.010	0.096	0.202	0.048	7.10	25.17	6.81	0.54	0.83	1.73	1.19
T_5	0.322	1.255	0.303	0.073	0.085	0.018	0.104	0.212	0.081	7.16	27.88	11.33	0.63	0.90	1.84	1.23
T_6	0.327	1.307	0.580	0.075	0.085	0.021	0.105	0.216	0.085	7.26	29.04	12.88	0.66	0.93	1.92	1.28
T_7	0.330	1.337	0.584	0.077	0.085	0.027	0.114	0.222	0.088	7.33	29.72	12.98	0.68	0.95	1.95	1.30
General mean	**0.319**	**1.118**	**0.398**	**0.072**	**0.079**	**0.015**	**0.100**	**0.199**	**0.061**	**7.08**	**24.84**	**8.84**	**0.59**	**0.85**	**1.72**	**1.20**

Note : T_0 (Control), T_1 (NAA 40 ppm), T_2 (Boron 0.2%), T_3 (Molybdenum 0.05%), T_4 (NAA 40 ppm + Boron 0.2%), T_5 (NAA 40 ppm + Molybdenum 0.05%), T_6 (Boron 0.2% + Molybdenum 0.05%), T_7 (NAA 40 ppm + Boron 0.2% + Molybdenum 0.05%.

Absolute Growth Rate

As shown in Table 2, all treatments exhibited a higher AGR compared to the control throughout the growth period. This signifies the positive impact of NAA and micronutrients on the overall biomass accumulation rate. Notably, the combination of T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%) consistently resulted in the highest AGR, particularly during the rapid vegetative growth phases of 30-45 and 45-60 DAS.

This finding aligns with the observed increases in plant height, branching and leaf area, indicating that T_7 stimulated a higher rate of biomass partitioning to different plant parts. This higher AGR in T_7 can be attributed to the synergistic effects of NAA, boron and molybdenum on cell division, elongation, and overall metabolic activity leading to a faster rate of biomass accumulation. This was similar with previous studies on the effects of these growth regulators and micronutrients on various crops (Ramesh and Ramprasad, 2014; Pahare and Das, 2020; Verma *et al*., 2013; Singh and Singh, 2021).

Relative Growth Rate

RGR representing growth relative to the existing plant mass, provides insights into the efficiency of biomass accumulation. Table 2 illustrates that RGR peaked during the 30-45 DAS period indicating a phase of rapid and efficient growth. Similar to AGR, treatments T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%) and T_6 (B 0.2% + Mo 0.05%) consistently outperformed other treatments suggesting that these combinations enhanced the plant's ability to convert assimilated resources into new biomass efficiently.

This is similar to findings from previous research on the use of growth regulators and micronutrients in enhancing RGR in legumes (Singh and Singh, 2021; Nayak *et al*., 2020; Verma *et al*., 2013).

Net Assimilation Rate

NAR, which represents the plant's efficiency in converting light energy into dry matter per unit leaf area followed a similar trend to AGR and RGR. As shown in Table 2, NAR peaked during the 30-45 DAS period indicating a phase of high photosynthetic efficiency. Treatment T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%) consistently exhibited the highest NAR followed by T_6 (B 0.2% + Mo 0.05%) and T_5 (NAA 40 ppm + Mo 0.05%). This suggests that these treatments enhanced the plant's photosynthetic capacity leading to greater dry matter production per unit leaf area.

This is consistent with the findings of previous studies that the application of NAA enhanced photosynthetic efficiency and net assimilation rate in various crops (Islam and Jahan, 2016; Pahare and Das, 2020)

Crop Growth Rate

CGR, which represents the increase in dry matter per unit ground area, provides a measure of overall plant growth. As shown in Table 2, CGR followed a similar trend to AGR, peaking during the 30-45 and 45-60 DAS periods. Treatment T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%) consistently resulted in the highest CGR followed by T_6 and T_5. This finding highlights the cumulative effect of enhanced leaf area, photosynthetic efficiency and nutrient uptake on overall biomass production.

Which is consistent with the improvements in crop growth rates observed in previous studies that evaluated the effects of plant growth regulators and micronutrients on various legume species (Fateminick, 2016; Sharma *et al*., 2009; Kuan *et al*., 2016; Rosa *et al*., 2019)

Leaf Area Index

LAI which represents the ratio of leaf area to ground area is a crucial determinant of light interception and consequently, plant growth. As shown in Table 2, LAI peaked at 45 DAS, indicating a period of maximum light interception. Treatment T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%) consistently resulted in the highest LAI throughout the growth period, followed by T_6. This finding suggests that these treatments promoted greater leaf area development, leading to increased light interception and, consequently, higher photosynthetic rates and biomass production.

The findings from this study regarding the positive influence of NAA and micronutrients on leaf area expansion and LAI are in line with the results reported in previous research on various crop species (Fateminick, 2016; Kuan *et al*, 2016; Islam and Jahan, 2016).

Conclusion

Due of the synergistic effects of boron, molybdenum and NAA on several growth and physiological parameters of green gram, the combination treatment T_7 (NAA 40 ppm + B 0.2% + Mo 0.05%) performed better than the individual treatments. An integrated nutrition management strategy is crucial for optimizing green gram production as evidenced by the higher vegetative growth, dry matter accumulation and physiological efficiency seen in this kind of treatment. Further research is warranted to elucidate the underlying mechanisms responsible for the observed beneficial effects and to explore the broader applicability of this combined foliar application in enhancing the productivity of other leguminous crops

Author contributions

Samrat R. Dhadge: Conducted research trial, Observations, Data collection, Data analysis. Amol P. Solanke: Collect reviews, Data analysis, Interpretation of results, Draft manuscript preparation, study conception and design. Shashianand U. Kalbhor: Collect reviews, Writing, editing and reviewed manuscript. Bhushan J. Gawhale: Collect reviews, Writing, editing and reviewed manuscript. S.S. Shinde: Critically reviewed the manuscript and served as scientific advisor. All authors reviewed the results and approved the final version of the manuscript

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