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Evaluation of Humic Acid and Naphthalene Acetic Acid for Improving Growth and Morphological Characteristics of Green Gram (*Vigna radiata* L.)

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Abstract

Green gram (*Vigna radiata* L.) is a widely cultivated grain legume recognized for its high nutritional value and its role in maintaining soil fertility and agricultural sustainability. A field experiment was undertaken to investigate the effects of humic acid (HA), naphthalene acetic acid (NAA), and their combined applications on the growth characteristics of green gram. The study was conducted using a Randomized Block Design (RBD) consisting of sixteen treatment combinations, including a control, with three replications. Morphological parameters such as plant height, number of branches per plant, and dry matter accumulation were assessed at the harvest stage. The findings indicated that the application of HA and NAA significantly enhanced plant growth compared with the untreated control. The greatest plant height (55.00 cm) was obtained under treatments T3 and T7, while the control treatment recorded the minimum height (42.00 cm). Branch production also responded positively to the treatments, with T7 producing the highest number of branches (10.00 branches plant^{-1}), whereas the control exhibited only 6.00 branches plant^{-1}. Treatments T3, T6, T8, T9, T12, and T13 also showed superior branching performance with 9.00 branches plant^{-1}. A similar trend was observed for dry matter production, where T3, T7, T9, and T13 recorded the highest dry weight (10.00 g plant^{-1}), compared with 7.00 g plant^{-1} in the control. The improvement in growth parameters can be associated with enhanced nutrient availability, stimulation of physiological activities, increased photosynthetic efficiency, and greater biomass production resulting from the application of HA and NAA. The results clearly demonstrate that humic acid and naphthalene acetic acid, applied either alone or in combination, contribute substantially to the improvement of vegetative growth and dry matter accumulation in green gram. Among the treatments evaluated, T7, T3, and T13 consistently exhibited superior performance, suggesting their suitability for promoting growth and enhancing productivity of green gram under field conditions.

Introduction

Green gram (*Vigna radiata* L.), commonly known as mung bean, is one of the most important pulse crops cultivated in tropical and subtropical regions owing to its high nutritional value, short growth duration, and adaptability to diverse agro-climatic conditions. It is an important source of dietary protein and contributes significantly to food and nutritional security, particularly in developing countries. India is the world's largest producer and consumer of green gram, accounting for a substantial share of global pulse production (**FAOSTAT, 2024**). The seeds contain approximately 20–24% protein, 60–65% carbohydrates, 1.2–1.5% fat, and are rich in dietary fibre, vitamins, and essential minerals, making them an excellent source of plant-based nutrition (**Sehrawat et al., 2013**). In addition to its nutritional importance, green gram enhances soil fertility through symbiotic biological nitrogen fixation and serves as an important component of sustainable cropping systems (**Graham and Vance, 2003**).

Despite its economic significance, the productivity of green gram remains below its genetic potential due to poor soil fertility, nutrient deficiencies, and various biotic and abiotic stresses. Conventional fertilizer-based crop production often leads to low nutrient-use efficiency and adverse environmental effects. Therefore, sustainable crop management practices that improve plant growth while reducing dependence on chemical inputs have gained considerable attention in recent years (**du Jardin, 2015**).

Humic acid, a major component of soil organic matter, has emerged as an effective plant bio-stimulant because of its positive effects on soil fertility and plant growth. It improves soil structure, increases nutrient availability, enhances microbial activity, stimulates root growth, and promotes nutrient uptake and photosynthetic efficiency, thereby improving vegetative growth and biomass accumulation (**Canellas and Olivares, 2014**). Several studies have demonstrated that humic acid enhances plant growth, chlorophyll content, nutrient uptake, and yield in legumes and other field crops (**Nardi et al., 2021**).

Naphthalene acetic acid (NAA), a synthetic auxin, is widely used as a plant growth regulator to improve cell division, cell elongation, root initiation, vascular differentiation, flowering, and assimilate translocation. Appropriate application of NAA has been reported to improve vegetative growth, flowering, pod development, and yield by regulating physiological and biochemical processes in several crop species (**Taiz et al., 2018**). Auxins also influence source–sink relationships and improve the translocation of photosynthates, resulting in enhanced crop productivity (**Davies, 2010**).

Although numerous studies have reported the individual effects of humic acid and NAA on crop growth and productivity, information regarding their combined influence on the growth and morphological characteristics of green gram under field conditions remains limited. Understanding their interactive effects may provide an environmentally sustainable approach for improving crop performance and productivity.

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Therefore, the present study was undertaken to evaluate the effects of humic acid and naphthalene acetic acid on the growth and morphological characteristics of green gram. The findings are expected to provide scientific evidence for optimizing the use of these growth-promoting substances in sustainable green gram cultivation.

Materials and Methods:

The field experiment was conducted during the Kharif seasons of 2023 and 2024 at the Department of Botany and Research Centre, Padmashri Vikhe Patil College of Arts, Science and Commerce, Pravaranagar, Maharashtra. The study was laid out in a Randomized Block Design (RBD) with 16 treatments and three replications to evaluate the effects of humic acid (HA) and naphthalene acetic acid (NAA) on green gram. Standard agronomic practices were followed throughout the experiment. Morphological parameters, including plant height, number of branches, root nodules, and dry weight per plant, were recorded at 65 DAS using five randomly selected plants from each treatment. The collected data were statistically analyzed to determine the significance of treatment effects.

Effect of humic acid and NAA on Morphological traits in green gram(cm).

The application of humic acid (HA), naphthalene acetic acid (NAA), and their combinations exerted a significant influence on plant height, number of branches per plant, and dry weight at harvest compared with the untreated control (Table 4.2.2). The results revealed that all growth-promoting treatments enhanced vegetative growth and biomass accumulation in green gram.

a. Plant Height at Harvest

Plant height increased significantly with the application of HA and NAA treatments. The tallest plants were recorded in **T3 (55.00 cm)** and **T7 (55.00 cm)**, followed by **T13 (54.00 cm)** and **T5 and T10 (53.00 cm)**. In contrast, the control treatment (**T1**) produced the shortest plants (**42.00 cm**). The increase in plant height under HA and NAA treatments may be attributed to improved nutrient uptake, enhanced cell elongation, and increased metabolic activity stimulated by humic substances and auxin-like growth regulators. Similar observations have been reported by several researchers, who noted that humic acid and NAA promote stem elongation and vegetative growth through enhanced physiological processes.

The data presented in the graph revealed that the application of humic acid (HA), naphthalene acetic acid (NAA), and their combinations significantly enhanced plant height at harvest compared with the untreated control. Plant height ranged from **42.00 cm in T1 (Control)** to **55.00 cm in T3 and T7**, indicating a substantial improvement in vegetative growth due to growth regulator application. Treatments **T13 (54.00 cm)**, **T5 (53.00 cm)**, and **T10 (53.00 cm)** also recorded higher plant heights than the control. The increase in plant height may be attributed to improved nutrient absorption, enhanced cell elongation, and greater metabolic activity induced by humic acid and NAA. These findings suggest that the application of HA and NAA effectively stimulated stem growth and overall plant development, resulting in taller and more vigorous green gram plants at harvest (Graph 1).

The significant increase in plant height recorded under NAA treatments in the present study may be attributed to the growth-regulating properties of auxins, which promote cell division, cell elongation, and stem development. These findings are consistent with the reports of Jayalakshmi (1989), Parmar et al. (2011), and Balaji et al. (2019), who observed improved vegetative growth following the application of optimum concentrations of NAA.

The positive response of green gram plants to humic acid, particularly at concentrations of 300–400 ppm, may be associated with enhanced nutrient uptake, increased photosynthetic efficiency, and improved soil moisture retention. Similar observations were reported by Cheng et al. (1995), Padem and Ocal (1999), Ashraf et al. (2005), and Katkat et al. (2009), who highlighted the beneficial effects of humic substances on plant growth and productivity.

Furthermore, the enhancement in plant height observed in the present investigation could be related to the ability of humic acid to improve membrane permeability, stimulate cellular elongation, and facilitate nutrient translocation within the plant system. Comparable results have been documented by Santhi et al. (2003), Nandakumar et al. (2004), and Delfine et al. (2005). The combined application of humic acid and NAA resulted in a greater improvement in plant growth than their individual treatments, indicating a possible synergistic effect. This enhancement may be due to increased metabolic activity, efficient assimilate partitioning, and improved physiological processes, which is in agreement with the findings of Neware *et al.,* (2017), Unlu *et al.,* (2011), and Neri *et al.,* (2002).

b. Number of Branches per Plant at Harvest

The number of branches per plant was significantly affected by different treatments. The highest number of branches was observed in **T7 (10.00 branches plant^{-1})**, followed by **T3, T6, T8, T9, T12, and T13 (9.00 branches plant^{-1})**. The control treatment recorded the lowest branching (**6.00 branches plant^{-1}**). Enhanced branching under HA and NAA application may be associated with increased cell division, improved nutrient availability, and better translocation of assimilates within the plant. The synergistic effect of humic acid and NAA likely promoted the development of lateral buds, resulting in greater branch formation and a more vigorous plant canopy.

The data presented in the graph revealed that the application of humic acid (HA) and naphthalene acetic acid (NAA) significantly increased the number of branches per plant compared with the untreated control at harvest. The highest number of branches was recorded in **T7 (10.00 branches plant^{-1})**, followed by **T3, T6, T8, T9, T12, and T13 (9.00 branches plant^{-1})**. In contrast, the control treatment (**T1**) produced the lowest number of branches (**6.00 branches plant^{-1}**). Enhanced branching under HA and NAA treatments may be associated with increased cell division, improved nutrient availability, and better translocation of photosynthates, which promoted the development of lateral shoots. The greater number of branches contributed to improved canopy development and enhanced growth performance of green gram plants. Thus, the application of HA and NAA proved beneficial in promoting branch formation and vegetative growth at harvest (Graph 1).

The increase in the number of branches observed following humic acid application may be associated with its ability to improve nutrient availability and uptake, thereby promoting metabolic activity and cell proliferation in plants. Similar observations have been reported by Nandakumar et al. (2004), who documented enhanced vegetative growth with humic acid treatments. The stimulatory effect of NAA on branching may be attributed to its auxin-like activity, which regulates cell division, cell elongation, and overall shoot development. These findings are in agreement with the reports of Jayalakshmi (1989), Parmar et al. (2011), and Balaji et al. (2019), who noted significant improvements in vegetative growth and branch formation in leguminous crops following NAA application. Furthermore, the combined application of humic acid and

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NAA exhibited a synergistic influence on branch development, resulting in superior performance compared to their individual applications. This observation corroborates the findings of Neware *et al.,* (2017), who reported enhanced growth attributes in crops receiving combined treatments of humic acid and NAA.

c. Dry Weight per Plant at Harvest

Dry matter accumulation was significantly increased by the application of HA and NAA. The maximum dry weight per plant was recorded in **T3, T7, T9, and T13 (10.00 g plant^{-1})**, whereas the control treatment produced the lowest dry weight (**7.00 g plant^{-1}**). Treatments receiving growth-promoting substances accumulated greater biomass due to improved photosynthetic efficiency, enhanced root growth, and increased uptake of nutrients and water. The higher dry matter production observed in these treatments reflects improved plant vigor and overall growth performance.

Overall, the results demonstrated that the application of humic acid and NAA, either individually or in combination, substantially improved growth attributes of green gram. Among the treatments, **T7**, **T3**, and **T13** were particularly effective in enhancing plant height, branch production, and dry matter accumulation at harvest, indicating the beneficial role of these growth regulators in improving crop growth and productivity.

The data presented in the graph revealed that the application of humic acid (HA) and naphthalene acetic acid (NAA) significantly improved plant dry weight compared with the untreated control at harvest. Dry matter accumulation was highest in **T3, T7, T9, and T13 (10.00 g plant^{-1})**, while the control treatment (**T1**) recorded the lowest dry weight (**7.00 g plant^{-1}**). Most of the remaining treatments produced dry weights ranging from **8.00 to 9.00 g plant^{-1}**, indicating a positive response to growth regulator application. The increase in dry weight may be attributed to enhanced photosynthetic activity, improved root growth, efficient nutrient uptake, and greater accumulation of assimilates within plant tissues. The results indicate that HA and NAA treatments promoted biomass production and plant vigor, leading to greater dry matter accumulation and improved overall crop growth at harvest (Graph).

The enhanced dry matter accumulation observed in the present study may be attributed to the beneficial effects of humic acid on nutrient uptake, photosynthetic activity, and overall plant metabolism. Similar findings have been

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reported by Ashraf et al. (2005), Katkat *et al.,* (2009), Unlu *et al*. (2011), Waqas *et al.,* (2014), Pandian *et al*., (2020) and El-Rheem *et al.,* (2024), who documented significant improvements in biomass production and dry matter accumulation following humic acid application in various crops. Furthermore, the superior performance of the combined treatments, particularly T8, T11, and T13, suggests a synergistic interaction between humic acid and NAA. This combined effect may have enhanced physiological and biochemical processes, resulting in greater biomass production compared with individual applications. These observations are in agreement with the findings of Neware *et al.,* (2017), who reported that the combined use of humic acid and NAA was more effective in improving growth and yield-related attributes than their separate application.

Table 1. Effect of Humic Acid and NAA on Plant Height, Number of Branches and Dry Weight at Harvest.

Treatment (HA/NAA)	Plant height (cm) at harvest	Number of branches Plant^{-1} at harvest	Dry Weight plant (g) at harvest
T1-Control	42.00	6.00	7.00
T2	52.00	7.00	8.00
T3	55.00	9.00	10.00
T4	52.00	8.00	9.00
T5	53.00	7.00	9.00
T6	52.00	9.00	9.00
T7	55.00	10.00	10.00
T8	50.00	9.00	9.00
T9	51.00	9.00	10.00
T10	53.00	8.00	9.00
T11	51.00	8.00	9.00
T12	51.00	9.00	9.00
T13	54.00	9.00	10.00
T14	52.00	8.00	9.00
T15	52.00	8.00	9.00
T16	52.00	8.00	9.00
SE(m) ±	0.38	0.24	0.26
CD at 5%	1.07	0.68	0.73

T1 = Control, T2–T4 = HA (300–500 ppm), T5–T7 = NAA (20–60 ppm), T8–T10 = 300 HA + NAA (20–60 ppm), T11–T13 = 400 HA + NAA (20–60 ppm), T14–T16 = 500 HA + NAA (20–60 ppm). HA = humic acid, NAA = naphthalene acetic acid; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, ns- non significant.

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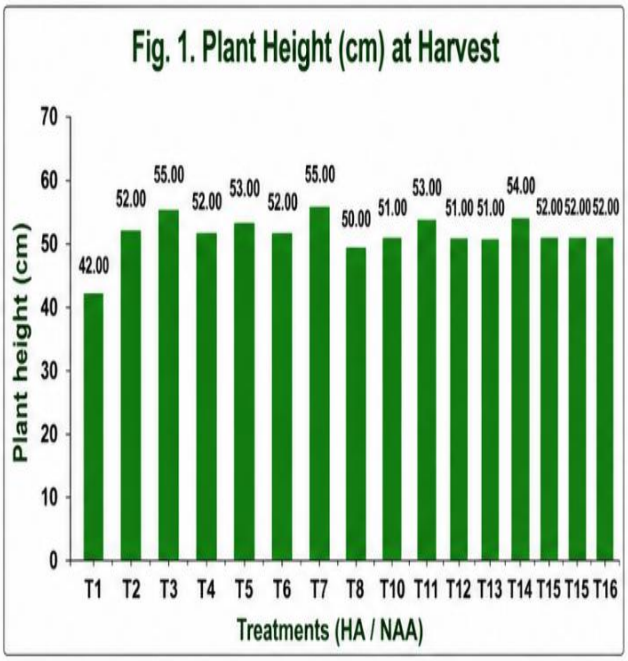

Fig. 1. Plant Height (cm) at Harvest

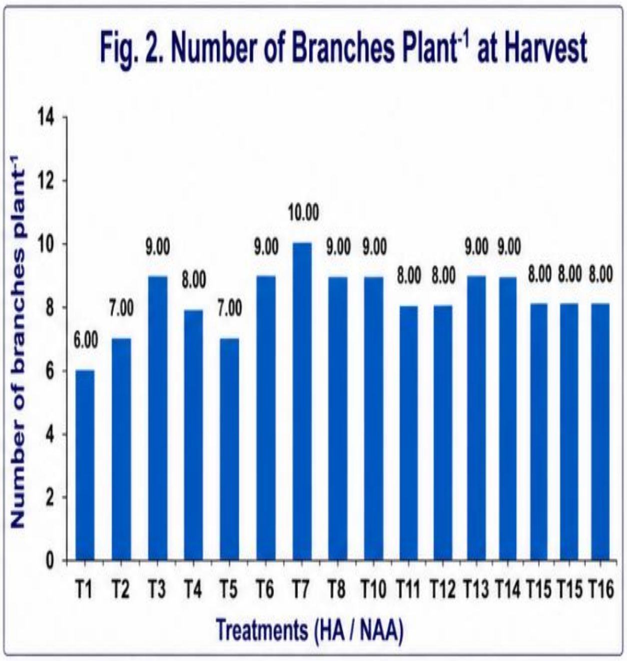

Fig. 2. Number of Branches Plant^{-1} at Harvest

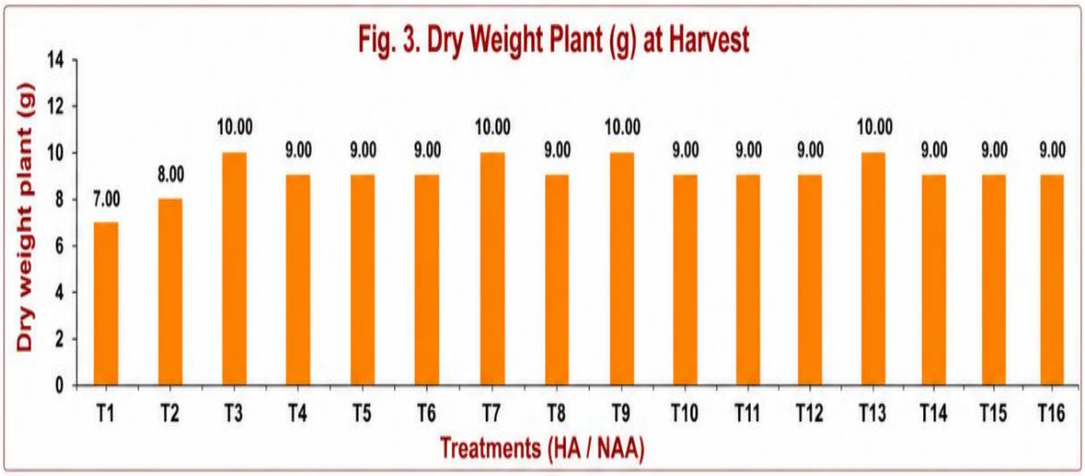

Fig. 3. Dry Weight Plant (g) at Harvest

TREATMENTS: T1-Control, T2-HA 300 ppm, T3-HA 400 ppm, T4-HA 500 ppm, T5-NAA 20 ppm, T6-NAA 40 ppm, T7-NAA 60 ppm, T8-HA 300 + NAA 20 ppm, T9-HA 300 + NAA 40 ppm, T10-HA 300 + NAA 60 ppm, T11-HA 400 + NAA 20 ppm, T12-HA 400 + NAA 40 ppm, T13-HA 400 + NAA 60 ppm, T14-HA 500 + NAA 20 ppm, T15-HA 500 + NAA 40 ppm, T16-HA 500 + NAA 60 ppm

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