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EFFECT OF RHIZOBIUM INOCULATION AND CHEMICAL FERTILIZER ON GROWTH AND YIELD OF LENTIL GENOTYPES IN GANGES TIDAL FLOODPLAIN SOIL

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Abstract

A field experiment was conducted in Rahmatpur, Barishal, within the Ganges Tidal Floodplain, to evaluate the effect of *Rhizobium* inoculant and chemical fertilizer on lentil (*Lens culinaris* L.) growth and yield. The study employed a split-plot design with three replications, investigating three lentil genotypes: BARI Masur-1, BARI Masur-7 and BD-3818, and five fertilizer treatments: Control, *Rhizobium* inoculum, recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB, recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum and 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum. Results indicated that the growing year did not significantly influence lentil growth and yield. BARI Masur-7 consistently outperformed the other genotypes, demonstrating superior performance across various growth and yield parameters including plant population, plant height, days to flowering and maturity, primary branches, fresh and dry weight of leaves and roots, number of pods per plant, number of seeds per pod, thousand-seed weight, seed yield, stover yield, biological yield, and harvest index. Furthermore, BARI Masur-7 exhibited a lower incidence of foot rot and Stemphylium blight. The most effective treatment combination for BARI Masur-7 was found to be 50% of the recommended chemical fertilizer $N_{10}P_{7.5}K_{12.5}S_5Zn_1B_{0.75}$ kg ha^{-1} combined with *Rhizobium* inoculum (30g/kg seed). This combined approach resulted in the highest seed yield (1636 kg ha^{-1}), highest harvest index (46.9%), and a favorable benefit-cost ratio (3.84). Additionally, this treatment significantly reduced the incidence of Foot rot (1.16%) and Stemphylium blight (0.33 on a 0-5 scale) compared to other treatments. These findings highlight a promising and sustainable approach for enhanced lentil production in the Ganges Tidal Floodplain soil.

Keywords: Disease incidence, *Lens culinaris* L., growth, profitability, yield contributing characters.

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Introduction

Lentil (*Lens culinaris* L.) is a vital pulse crop in Bangladesh (Aktar *et al*., 2019), accounting for 40% of the country's cultivated pulse area and serving as a preferred food and nutrition source (BBS, 2019). Lentils, popularly known as Poorman's meat, are used to prepare an inexpensive and nutritious split with rice (*Hotchpoch*) all over Bangladesh, which provide more complete protein. Globally, lentil plays a crucial role in food and nutritional security due to its high protein content, carbohydrate, vitamin B complex and minerals and ability to enrich soil through biological nitrogen fixation (Khazaei *et al*., 2019). Despite its importance, the per capita pulse consumption in Bangladesh (12 g day^{-1}) is significantly lower than the WHO's recommended intake (45 g day^{-1}), highlighting a critical nutritional gap. Bridging this gap necessitates increasing pulse production through effective fertilizer management and the adoption of high-yielding varieties.

Lentil cultivation in Bangladesh is concentrated in the ecologically sensitive Ganges Tidal Floodplain area. This region presents unique agricultural challenges due to its distinct hydrological regime and dynamic soil properties. The soils, primarily silty clay loam to clay, exhibit varying degrees of alkalinity and salinity. These soils often suffer from nutrient imbalances and deficiencies, particularly in phosphorus, sulfer, zinc, and boron, which restrict crop growth and yield (Rahman *et al.,* 2023). Furthermore, the area is susceptible to waterlogging, flash floods, and increasing climate change impacts like sea-level rise and exacerbated salinity intrusion, all of which complicate sustainable agricultural practices (Gopalakrishnan *et al.,* 2019).

To address these challenges and boost lentil productivity, effective nutrient management is paramount. Traditional approaches often rely on imbalanced or excess chemical fertilizer use, leading to environmental concerns, increased production costs, and potential long-term soil degradation (Krasilnikov *et al.,* 2022). A more sustainable alternative involves leveraging the symbiotic relationship between lentil plants and nitrogen-fixing *Rhizobium* bacteria. *Rhizobium* inoculation can significantly reduce dependence on synthetic nitrogen fertilizers, improve soil health, and contribute to environmentally friendly agriculture (Quddus *et al.,* 2024). The effectiveness of *Rhizobium* inoculation can vary based on soil type, environmental conditions and lentil genotype. The unique characteristics of the Ganges Tidal Floodplain soil, including its fluctuating salinity and water regimes, may influence Rhizobial survival, nodulation, and nitrogen fixation efficiency. Currently, there is a lack of research on how *Rhizobium* inoculation interacts with chemical fertilizer application in this specific soil type. Understanding this interaction is crucial for optimizing nutrient management. Additionally, evaluating different lentil genotypes under these varying management regimes is essential to identify the best varieties for the region's challenging conditions. This study aims to investigate the effect of *Rhizobium* inoculation and varying levels of chemical fertilizer application on the growth and yield of different lentil genotypes cultivated in the Ganges Tidal Floodplain soil. The findings will provide valuable insights into the sustainable intensification of lentil production in this ecologically sensitive and agriculturally important region, ultimately contributing to improved food and nutritional security and farmer livelihoods.

Materials and methods

A field experiment was conducted during Rabi season of two consecutive years 2014-15 and 2015-16 at the Agronomy research field of Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Rahmatpur, Barishal (22°48' N, 90°18' E). The study area is located within the Ganges Tidal Floodplain (AEZ-13). This well-drained, medium-high land features even topography and a clay loam texture. The soil is characterized by low organic matter content (0.94%), a neutral soil reaction (pH: 6.9), low total nitrogen content (0.043%), available P (10.6 $\mu g\ g^{-1}$), S (2.9 $\mu g\ g^{-1}$), B (0.16 $\mu g\ g^{-1}$), exchangeable K (0.16 meq. $100g^{-1}$) and is slightly saline (1.20 dS/m). The experimental area experiences a sub-tropical, dry or savanna climate. The average annual temperature is approximately 28.8°C, which is slightly higher than the average for Bangladesh. The region receives significant rainfall, averaging 46.9 mm annually over approximately 95.6 mm in rainy days.

The land was prepared using a tractor-driven chisel plough. This involved three rounds of ploughing and cross-ploughing, followed by laddering, to achieve the optimal soil tilth. The experimental treatments were structured with two factors: Factor A (main plot) five levels of fertilizer application *viz*., T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed). Factor B (Sub-plot) three different genotypes viz. G_1 = BARI Masur-1, G_2 = BARI Masur-7 and G_3 = BD-3818. The seeds of different genotypes were collected from Pulse Research Centre, BARI, Ishordi, Pabna, and the *Rhizobium* inoculum was collected from the Division of Soil Science, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh.

The experiment was designed as a split-plot with three replications. The experimental area was firstly divided into three large blocks and then each block was further divided into five main plots. Subsequently, each main plot was subdivided into three smaller sub-plots. Fertilizer levels were randomly assigned to the main plots, while different genotypes were assigned to the sub-plots. Each individual plot measured 3 meters by 6 meters, with a 1-meter border separating plots and a 2-meter border between replications. In total, the experiment was comprised of 45-unit plots. Nutrients N, P, K, S, Zn and B were applied treatment wise as urea, TSP, MoP, gypsum, zinc sulphate (heptahydrate) and boric acid; respectively during final plot preparation.

Before sowing, the seeds were first lightly coated with molasses. This sticky layer helped the bio-fertilizer adhere better to the seeds when it was subsequently mixed at a rate of 30 grams per kilogram of seeds. After thorough mixing, the inoculated seeds were stored in a cool, dry place to prevent them from clumping together. Before sowing, seeds were treated with Provex-200 at 2.5 g/kg seeds to control the seed-borne diseases. Treatment wise seeds were sown at 35 kg ha^{-1} in rows by hand with the spacing of 30 cm × continuous placing in the second week of November in both years. Weeds were controlled, plants were thinned, irrigation was provided, and plant protection measures were taken as needed. The crop was harvested once 90% of the plants and pods had turned brown to black. After harvest, the crop bundles were sun-dried on a threshing floor. Seeds were then separated from the plants by beating the bundles with bamboo sticks. A winnower was used to separate the grain from the straw. Finally, the dry seeds and stover from each plot were weighed and the yields were converted to kilograms per hectare.

Data collection and recording were done properly: For plant population, a one-square-meter area was marked with rope in each plot. Plants within this area were counted 20 days after sowing (DAS) to determine the number of plants per square meter. Plant height was measured on ten randomly selected plants from outside the harvest area at 20, 40, 60, and 80 DAS. Measurements were taken from ground level to the tip of the plant and recorded in centimeters. The number of primary branches was counted at harvest on the same ten selected plants. Days to first flowering and 50% flowering were recorded by visual observation. Days to maturity was recorded when plant growth ceased and 90% of the plants and pods had turned from straw to black. At 50 DAS, ten plants were randomly selected from outside the harvest area in each unit plot, tagged, uprooted, and brought to the laboratory. Fresh leaves were separated from each branch, and their fresh weight was determined in grams using an electric balance. The collected fresh leaves were then oven-dried at 70°C for 72 hours. After cooling, their dry weight was also measured in grams with an electric balance. At 80 DAS, ten plants were randomly selected from outside the harvest area in each unit plot and tagged. The roots were cut, stored in paper bags, washed, and cleaned. Their fresh root weight was determined in grams. These root samples were then oven-dried at 70°C for 72 hours. After cooling, their dry root weight was measured in grams using an electric balance. At maturity, the number of pods per plant was counted on the same ten selected plants in each treatment. From these ten sampled plants, ten randomly selected pods were collected, and the number of seeds per pod was counted. Finally, a composite sample from each treatment was used to determine thousand seed weight. One thousand seeds were counted and weighed using a digital electric balance. The weight was adjusted to 9% moisture content and recorded in grams.

The incidence of foot rot, caused by *Fusarium oxysporum* Schltdl., was recorded at 25, 50, and 75 DAS. This was determined by counting the number of foot rot infected plants per square meter area and the percentage of incidence was then calculated using the following formula:

$$\textbf{Incidence of foot rot}\ (\%) = \frac{\text{Number of foot rot infected plants}\ /\mathbf{m^2}}{\text{Total number of plants}\ /\mathbf{m^2}} \times \mathbf{100}$$

The incidence of Stemphylium blight, caused by *Stemphylium botryosum*, was assessed twice: once before flowering and again after pod formation. A 0-5 point scoring scale (Bakr and Ahmed, 1992) was used to evaluate the level of infection, where: 0 = highly resistant, 1 = resistant, 2 = moderately resistant, 3 = moderately susceptible, 4 = susceptible, and 5 = highly susceptible, whereas Biological yield and Harvest index were calculated using the following formula:

(i) Biological yield (kg ha^{-1}) = Grain yield + Stover yield

(ii) HI (%) = $\frac{\textbf{Seed yield}}{\textbf{Seed yield+Stover yield}} \times 100 = \frac{\textbf{Economic yield}}{\textbf{Biological yield}} \times 100$ (Donald, 1963).

Cost and return analysis: For each treatment, the total variable cost (TVC) per hectare for lentil cultivation was determined, encompassing expenses for labor, plowing, fertilizers, seeds, and pesticides. Land rental costs were excluded from this analysis. Gross return per hectare was calculated by multiplying the seed yield (converted to kg ha^{-1}) by the current market price. Net return was then calculated by subtracting the TVC from the gross return. Finally, the benefit-cost ratio (BCR) was determined using the following formula: BCR = Gross Return ÷ Total Variable Cost.

Statistical analysis: The collected data were subjected to statistical analysis of variance (ANOVA) using the open-source software R (version 3.5.2; Vienna, Austria; https://www.R-project.org/). To compare the means of all data, the least significant difference (LSD) test was applied within the R statistical model at 5% level of probability.

*Weather and climat*e

Some weather data were collected from the RARS, Bangladesh Agricultural Research Institute (BARI), Rahmatpur, Barishal for the experimentation (Fig. 1).

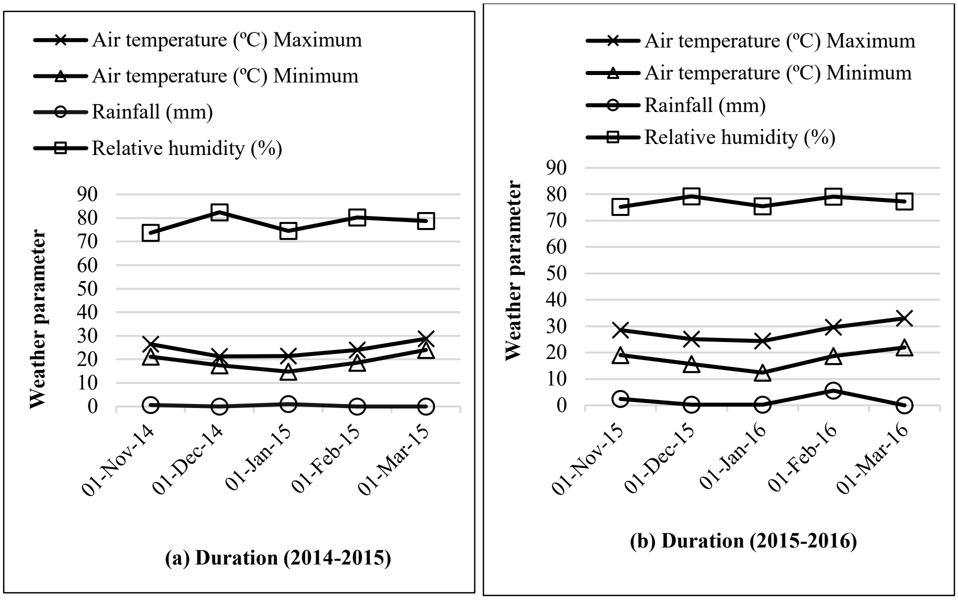


Fig. 1 (a, b). Monthly average of maximum, minimum air temperature, rainfall and relative humidity during the *Rabi* season in 2014-2015 and 2015-2016at RARS, Barishal.

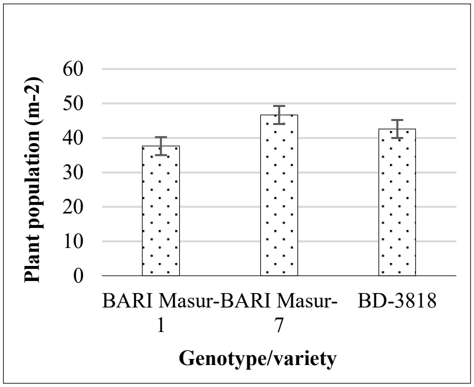
Results and Discussion

Effect of growing year on the growth and yield attributes of lentil

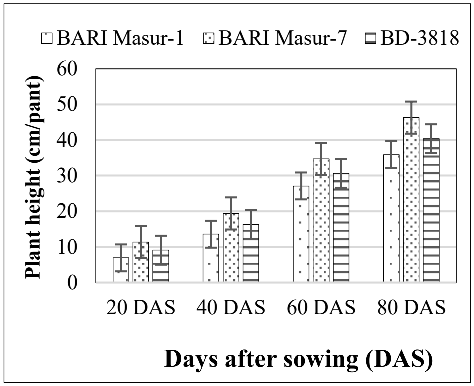
Lentil growth and yield attributes remained consistent, showing no significant difference between the growing seasons of 2014-15 and 2015-16 (Data not presented).

Effect of genotype/variety on the growth and yield attributes of lentil

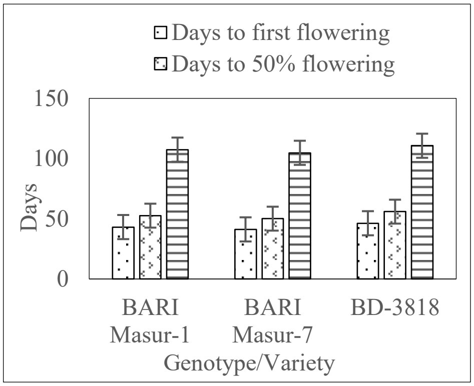
Fig. 2 shows that BARI Masur-7 exhibited significantly superior performance compared to BD-3818 and BARI Masur-1 in respect to plant population m^{-2}, plant height, primary branches plant^{-1}, fresh and dry weight of leaf and root, number of pods plant^{-1}, number of seeds pod^{-1}, thousand seed weight, yield and harvest index. Furthermore, BARI Masur-7 showed fewer days to flowering and maturity, and a lower incidence of Foot rot and Stemphylium blight.



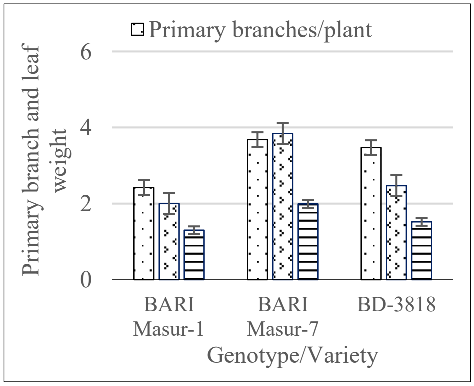
(a) Effect of genotype on plant population



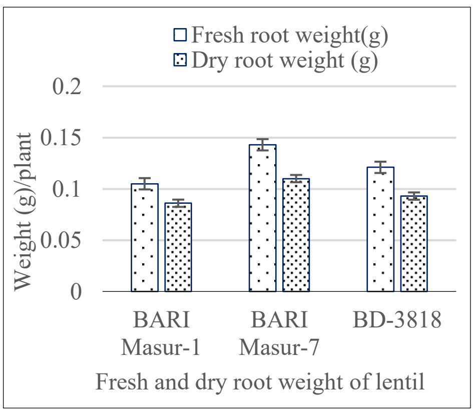
(b) Effect of genotype on plant height



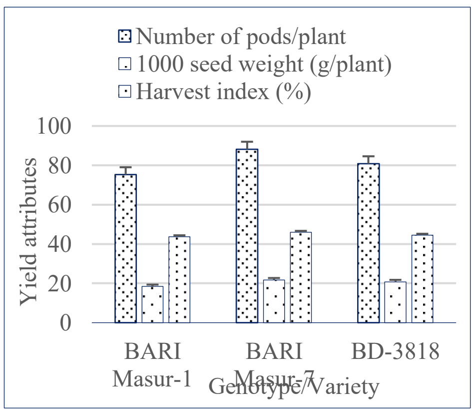
(c) Effect of genotype on flowering and maturity



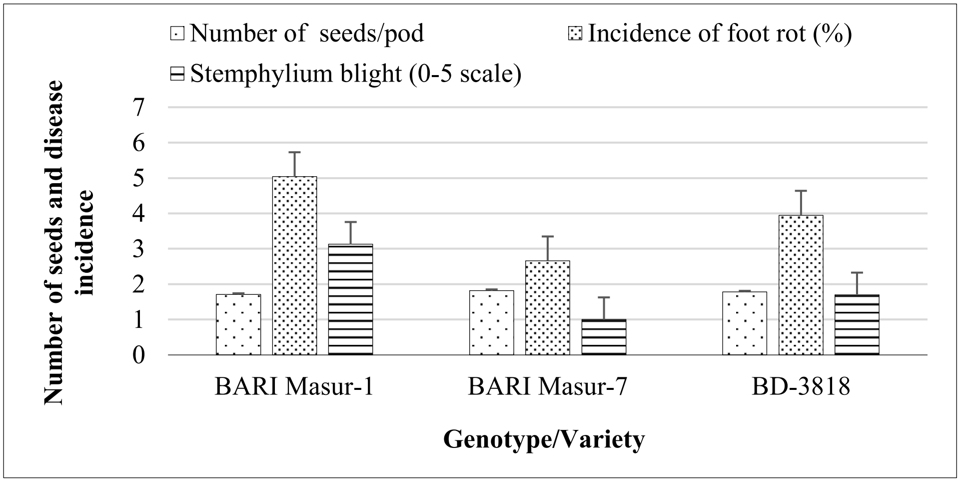
(d) Effect of genotype on 1° branch and leaf weight



(e) Effect of genotype on root weight of lentil



(f) Effect of genotype on yield attributes of lentil



(g) Effect of genotype on number of seeds/pod and disease incidence

Fig. 2 (a-g) Effect of genotype/variety on the growth, yield attributes and yields of lentil. Vertical bar indicates standard error of mean at 5% level of significance by LSD test.

Effect of Rhizobium inoculation and chemical fertilizers on growth and yield attributes of lentil

Lentil plant population and height were significantly affected by various fertilizer management practices (Table 1). The highest plant population (49.2) was observed in treatment T_5, which involved applying 50% of 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB kg ha^{-1} along with *Rhizobium* inoculum (30 g/kg seed). The highest plant population observed with a combination of 50% inorganic fertilizer and *Rhizobium* inoculation is likely due to the bacteria's ability to enhance seed germination and seedling survival. *Rhizobium*, nitrogen-fixing bacteria, plays a crucial role in promoting healthy plant growth and population, by converting atmospheric nitrogen into a usable form for the plant. This symbiotic relationship between *Rhizobium* and legume can significantly increase plant vigor and population (Argaw, 2017). In contrast, the control treatment (T_1) had the lowest population (35.8). Lentil plant height significantly increased with plant age, showing a sharp rise up to 80 days after sowing (DAS) across all fertilizer treatments (Table 1). The tallest plants (47.6 cm) were observed in the T_5 treatment, while the control treatment had the shortest plants (34.8 cm) at 80 DAS.

Table 1. Effect of fertilizer management practices on plant population and plant height of lentil genotypes

Treatment	Plant population/m^2 at 20 DAS	Plant height (cm)			
		20 DAS	40 DAS	60 DAS	80 DAS
T_1	35.8	7.00	13.3	26.1	34.8
T_2	42.3	9.07	16.6	30.5	40.2
T_3	38.9	8.97	16.1	28.9	38.3
T_4	45.2	9.25	16.9	32.5	43.4
T_5	49.2	11.2	19.1	36.1	47.6
LSD (0.05)	3.01	0.35	0.61	1.53	1.09
CV (%)	10.08	5.38	5.28	7.04	3.79

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation, DAS= Days after sowing. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).

Many researchers have reported that *Rhizobium* inoculation and fertilizer application significantly boost all growth parameters in legume crops. For instance, Malik *et al.* (2014) found a maximum significant increase ($P \leq 0.05$) in mungbean plant height when compost, *Rhizobium*, and nitrogen were applied together. Plant height varies among different varieties. In line with the findings, BARI Masur-7 exhibited the tallest plants in our study.

As presented in Table 2, fertilizer management practices significantly impacted several lentil growth parameters, including days to flowering and maturity, primary branches plant^{-1} and the fresh and dry weights of leaves and roots. The T_5 treatment significantly extended the time for lentil to reach its first flowering (46.9 days), 50% flowering (56.3 days), and full maturity (111 days). In contrast, the control treatment led to the quickest progression through

these developmental stages. While some literature indicates that higher nitrogen availability can prolong the vegetative phase and thus shorten the reproductive phase, it is also recognized that genotypic variations influence days to flowering. In this study, the T_5 treatment produced the maximum number of primary branches per plant (4.10), closely followed by the T_4 treatment. The control treatment, however, resulted in the fewest primary branches (2.42) (Table 2).

Table 2. Effect of fertilizer management practices on days to flowering, days to maturity, primary branches plant^{-1}, fresh and dry leaf weight, fresh and dry root weight of lentil genotypes

Treatment	Days to flowering		Days to maturity	Primary branches plant^{-1} at harvest	Fresh leaf weight (g) at 50 DAS	Dry leaf weight (g) at 50 DAS	Fresh root weight (g) at 80 DAS	Dry root weight (g) at 80 DAS
	First	50%						
T_1	40.3	49.7	105	2.42	1.96	1.29	0.10	0.08
T_2	43.1	52.2	108	2.85	2.70	1.63	0.11	0.09
T_3	42.4	51.9	107	2.66	2.54	1.48	0.11	0.09
T_4	44.8	54.2	108	3.92	2.89	1.73	0.12	0.10
T_5	46.9	56.3	111	4.10	3.43	1.90	0.13	0.11
LSD (0.05)	0.70	0.90	0.44	0.23	0.11	0.07	0.003	0.002
CV (%)	2.29	2.41	0.58	10.2	5.95	6.39	4.65	3.09

Means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).

These findings align with existing research on branching in plants. Rahman *et al*. (2013) reported that branching is both a genetic characteristic and is influenced by environmental factors. Awal and Roy (2015) also confirmed that the number of branches can vary among different varieties. At 50 days after sowing (DAS), the T_5 treatment resulted in significantly the highest fresh leaf weight (3.43 g) and dry leaf weight (1.90 g), while the control treatment exhibited the lowest weights (Table 2). Significantly, the highest root fresh weight (0.13 g) and root dry weight (0.11 g) were observed in the T_5 treatment at 80 days after sowing (DAS) (Table 2). Conversely, the lowest root fresh and dry weights were recorded in the control treatment at 80 DAS. Our results indicate that lentil fresh and dry root weight largely depends on early root system development and nodule production. This also varies between varieties due to their genetic makeup. Notably, BARI Masur-7 exhibited higher individual root weight compared to BARI Masur-1 and BD-3818. The highest dry root weight was observed in BARI Masur-7 plots treated with 50% inorganic fertilizer + inoculants (T_5). This suggests that the combined application of inoculants and chemical fertilizers likely triggered an enhanced nodulation process, leading to a greater number of nodules and consequently, higher dry matter production.

Table 3 clearly demonstrates that the fertilizer management practices significantly influenced the yield attributes of lentil and the incidence of *Stemphylium* blight disease. However, these practices did not have a significant impact on the incidence of foot rot disease. In this study, significantly the maximum number of pods plant^{-1} (92.5) was recorded in T_5, which involved applying 50% of inorganic 10-7.5-12.5-5-1-0.75 kg ha^{-1} along with *Rhizobium* inoculum (30 g/kg seed) and the lowest (69.4) was in control treatment. Research consistently shows that the number of pods per plant is a significant factor in determining lentil yield.

Table 3. Effect of fertilizer management practices on the number of pods plant^{-1}, number of seeds pod^{-1}, thousand seed weight, Incidence of foot rot and *Stemphylium* blight of lentil genotypes

Treatment	Number of pods plant^{-1}	Number of seeds pod^{-1}	Thousand seed weight (g)	Incidence of foot rot (%)	*Stemphylium* blight (0-5 scale)
T_1	69.4	1.67	19.9	5.63	2.83
T_2	81.9	1.78	20.4	3.78	1.88
T_3	76.0	1.74	20.0	4.41	2.33
T_4	87.3	1.81	20.5	3.35	1.55
T_5	92.5	1.85	20.7	2.26	1.11
LSD (0.05)	2.15	0.03	0.10	NS	0.32
CV (%)	3.74	2.55	0.76	27.7	23.5

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).

Our findings align with those of Sonkarlay *et al.* (2020), who observed the highest pod count (164 pods per plant) in lentils when chemical fertilizers were combined with biofertilizers and organic fertilizers. Further supporting this, studies by Datta et al. (2013) concluded that lentil seed yield is positively correlated with the number of pods per plant. This strong relationship underscores the importance of optimizing conditions for robust pod development. It is also worth noting that lentil genotypes themselves play a significant role in pod formation, with different varieties exhibiting varying capacities for pod production. Beyond lentils, the beneficial effects of bio-fertilizers on pod count are well-documented. In case of number of seeds pod^{-1}, significantly the highest number of seed (1.85) was found in T_5 treatment and the lowest (1.67) was in control (Table 3). Sonkarlay *et. al*., (2020) reported that the number of seeds pod^{-1} (2.57) was the highest when applied 75% RDP+ farmyard manure @ 5 t/ha + biophos @ 20 ml/kg seed. Datta *et al*. (2013) found that the numbers of filled pods differ with varieties.

The weight of a thousand seeds, a key indicator of lentil quality and yield, was significantly impacted by different fertilizer management in our study. The highest thousand-seed weight (20.7 g) was observed in treatment T_5, while the lowest (19.9 g) came from the control treatment (Table 3). The application of inoculants alongside chemical fertilizers likely plays a crucial role by ensuring optimal nutrient availability, which in turn supports the development of heavier grains.

The effect of fertilizer management practice on the incidence of foot rot was insignificant and the incidence of foot rot ranged from 2.26 to 5.63% (Table 3). Hannan *et al*. (2012) reported that post-emergence deaths of plants due to foot rot disease were significantly reduced after combined seed treatment with BINA-bio-fertilizer and BAU-bio-fungicide. *Stemphylium* blight significantly impacted lentil health in our study. The control treatment exhibited the highest *Stemphylium* blight disease score (2.83), indicating severe susceptibility, while the T_5 treatment demonstrated the lowest score (1.11), suggesting a strong suppressive effect (Table 3). This highlights the crucial role of effective management practices in mitigating this disease. Our findings align with previous research on varietal resistance. Alam (2016) reported that certain lentil varieties show varying degrees of susceptibility to *Stemphylium* blight under field conditions. For instance, local varieties were highly susceptible, BARI Masur-3 and BARI Masur-4 showed moderate susceptibility, whereas BARI Masur-5, BARI Masur-6, and notably, BARI Masur-7 exhibited moderate resistance. This reinforces the importance of selecting resilient lentil genotypes, combined with appropriate fertilizer strategies, to minimize *Stemphylium* blight incidence.

Table 4 illustrates that lentil yields and harvest index were significantly influenced by the various fertilizer management practices. The T_5 treatment recorded the highest seed yield (1468 kg ha^{-1}), while the control treatment exhibited the lowest yield (1025 kg ha^{-1}). This finding was corroborated by Sonkarlay *et al.* (2020), who reported a superior seed yield (1550 kg ha^{-1}) in lentil when a combination of chemical, bio-fertilizer, and organic fertilizer was utilized. Similarly, Singh *et al*. (2013) documented significantly enhanced physiological parameters and grain yield (1236 kg ha^{-1}) in lentil treated with vermicompost (4 t ha^{-1}) in conjunction with *Rhizobium* and phosphate-solubilizing bacteria. Previous reports also indicated better growth with a combination of organic and inorganic fertilizers compared to inorganic fertilizers alone.

The T_5 treatment consistently outperformed the control in several yield parameters. Specially, T_5 yielded the highest stover (1721 kg ha^{-1}) compared to the control's 1341 kg ha^{-1}. This finding aligns with observations by Sonkarlay *et al.* (2020), where they reported even higher stover yields (1903 kg ha^{-1}) when a combination of chemical, bio-fertilizer and organic fertilizers was applied, suggesting a potential for further optimization beyond the T_5 treatment. Beyond stover yield, T_5 also demonstrated a significantly higher biological yield (3188 kg ha^{-1}) than the control (2366 kg ha^{-1}). This superior performance extended to the harvest index, with T_5 achieving the highest (46.0%) compared to the control's lowest (43.3%) (Table 4). These results collectively indicate that the T_5 treatment positively influenced the overall biomass production and the efficiency of partitioning this biomass into harvestable yield.

Table 4. Effect of fertilizer management practice on seed yield, stover yield, biological yield, and harvest index of lentil genotypes

Treatments	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
T_1	1025	1341	2366	43.3
T_2	1319	1622	2944	44.7
T_3	1249	1562	2811	44.4
T_4	1396	1663	3059	45.6
T_5	1468	1721	3188	46.0
LSD (0.05)	15.5	19.6	34.9	0.09
CV (%)	1.70	1.75	1.72	0.30

The means in a column having the different letters is statistically significance at the 5% level using LSD test. LSD = least significant difference, CV = coefficient of variation. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).

Interaction effect of genotype and fertilizer management on the growth and yield attributes of lentil

Table 5 indicates that plant population did not exhibit significant variations as a result of the interaction between fertilizer management practices and lentil genotypes. This suggests that the combination of different fertilizer approaches and lentil varieties did not lead to statistically different plant densities. A significant interaction effect of fertilizer management practices and lentil genotype was observed on plant height up to 40 days after sowing (DAS). Beyond this point, specifically up to 80 DAS, plant height was not significantly affected by these interactions. This highlights the importance of early-stage interactions in determining lentil plant height. The highest plant height measurements at both 20 DAS (13.3 cm) and 40 DAS (23.2 cm) were recorded in the $T_5 \times G_2$ treatment combination (50% of inorganic $N_{10}P_{7.5}K_{12.5}S_5Zn_1B_{0.75}$ kg ha^{-1} + *Rhizobium* inoculum × BARI Masur-7). The lowest plant height was observed in the control × BARI Masur-1 treatment. The observed plant height data aligns with the previous findings, providing external validation for our results. The superior early growth (plant height) observed in the $T_5 \times G_2$ treatment combination strongly suggests that the integrated use of bacterial inoculums (*Rhizobium*) alongside chemical fertilizers plays a crucial role in actively regulating the early development of lentil under optimum conditions. The interaction of fertilizer management practices and genotype shows that the maximum number of days to reach first flowering, 50% flowering and maturity in lentil was observed in $T_5 \times G_3$ treatment combination (50% of inorganic 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum × BD-3818). On the other hand, the minimum days to first flowering, 50 percent flowering and maturity was in control × BARI Masur-7. These findings highlight that the $T_5 \times G_3$ treatment, which included *Rhizobium* inoculum alongside a partial dose of inorganic fertilizers, resulted in a longer vegetative phase and delayed reproductive development. While this might seem counterintuitive for early harvest, a prolonged growth period could potentially lead to greater biomass accumulation and, subsequently, higher yields, assuming favorable environmental conditions continue.

Table 5. Interaction effect of fertilizer management practices (T) × genotype (G) on lentil plant population, plant height, days to flowering and maturity

Treatment (T) × Genotype (G)	Plant population/m^2	Plant height (cm) at				Days to flowering		Days to maturity
		20 DAS	40 DAS	60 DAS	80 DAS	First	50%	
$T_1 \times G_1$	31.0	6.47	12.3	22.5	30.5	39.8	49.5	105
$T_2 \times G_1$	38.0	6.73	13.7	26.8	34.9	43.2	52.3	107
$T_3 \times G_1$	34.7	6.45	13.3	26.0	33.6	42.3	51.7	107
$T_4 \times G_1$	40.5	6.93	13.8	28.7	39.1	44.3	53.8	108
$T_5 \times G_1$	44.0	8.00	14.7	31.5	41.6	45.8	55.5	11
$T_1 \times G_2$	40.0	7.82	14.5	29.9	39.5	38.3	47.8	103
$T_2 \times G_2$	46.5	11.9	19.8	34.3	45.4	40.8	49.2	105
$T_3 \times G_2$	42.7	11.7	19.4	31.9	43.9	40.2	49.7	104
$T_4 \times G_2$	49.3	12.1	20.2	36.3	48.2	42.5	51.2	105
$T_5 \times G_2$	54.8	13.3	23.2	41.1	54.5	44.0	52.5	107
$T_1 \times G_3$	36.5	6.73	13.2	25.8	34.3	42.8	51.7	106
$T_2 \times G_3$	42.5	8.6	16.2	30.5	40.2	45.3	55.0	111
$T_3 \times G_3$	39.3	8.80	15.6	28.7	37.5	44.8	54.3	110
$T_4 \times G_3$	45.8	8.73	16.8	32.6	43.0	47.5	57.5	112
$T_5 \times G_3$	48.8	12.3	19.6	35.8	46.7	50.8	61.0	114
LSD (0.05)	NS	0.53	0.48	NS	NS	0.75	0.83	0.79
CV (%)	2.99	5.04	2.51	4.47	4.16	1.47	1.35	0.63

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).G_1= BARI Masur-1, G_2= BARI Masur-7 and G_3= BD-3818.

The *Rhizobium* inoculum might be contributed to a sustained nitrogen supply, raising vegetative growth before transitioning to flowering. In contrast, the rapid progression to flowering and maturity in the control × BARI Masur-7 treatment suggests that under nutrient-limited conditions, the plants accelerated their reproductive cycle, possibly as a survival mechanism to ensure seed production. BARI Masur-7 appears to be a genotype that inherently matures earlier, and this characteristic is amplified when nutrient availability is low.

Table 6 illustrates the interactive effects of fertilizer management practices and genotype on various lentil plant parameters. In terms of primary branches per plant, the maximum number (4.75) was observed in the $T_5 \times G_2$ treatment combination (50% of inorganic $N_{10}P_{7.5}K_{12.5}S_5Zn_1B_{0.75}$ kg ha^{-1} + *Rhizobium* inoculum × BARI Masur-7). Conversely, the lowest number of primary branches (2.06) was recorded in the control × BARI Masur-1 treatment. It is evident that treatments incorporating *Rhizobium* inoculums generally led to the production of more primary branches. Similar view corroborated by Basu *et al.* (2021). Significantly, the highest fresh and dry leaves weights were also registered in the $T_5 \times G_2$ treatment combination, measuring 4.45 g and 2.40 g, respectively. In contrast, the lowest fresh and dry leaf weights (1.49 g and 1.10 g) were found in the control × BARI Masur-1 treatment. Regarding root characteristics, no significant interaction effect of fertilizer management practices and lentil genotype was found on fresh root weight, with values ranging from 0.09 g to 0.14 g (Table 6). However, for dry root weight, the highest weight (0.112 g) was recorded in the $T_5 \times G_2$ treatment combination, while the lowest (0.08 g) was in the control × BARI Masur-1 treatment (Table 6). The results consistently highlight the beneficial impact of the $T_5 \times G_2$ treatment combination (50% inorganic fertilizer+ *Rhizobium* inoculum × BARI Masur-7) on several key growth parameters of lentil. The increased above growth parameters of lentil observed in *Rhizobium*-added treatments is highly significant. This is likely attributable to the enhanced availability of nitrogen, stemming from both biological nitrogen fixation facilitated by the *Rhizobium* inoculum and the supplementary application of nitrogenous chemical fertilizers. Nitrogen is a crucial nutrient for vegetative growth like branching, leaf and root growth directly contributing to a more robust plant architecture (Basu *et al.*, 2021).

Table 6. Interaction effect of fertilizer management practices (T) × genotype (G) on the lentil primary branches plant^{-1}, fresh and dry leaf weight, fresh and dry root weight

Treatment (T) × Genotype (G)	Primary branch plant^{-1} at harvest	Fresh leaf weight at 50 DAS (g)	Dry leaf weight at 50 DAS (g)	Fresh root weight at 80 DAS (g)	Dry root weight at 80 DAS (g)
$T_1 \times G_1$	2.06	1.49	1.10	0.09	0.077
$T_2 \times G_1$	2.13	2.02	1.30	0.11	0.086
$T_3 \times G_1$	2.11	1.80	1.19	0.11	0.081
$T_4 \times G_1$	2.75	2.15	1.36	0.11	0.092
$T_5 \times G_1$	3.03	2.57	1.55	0.12	0.094
$T_1 \times G_2$	2.68	2.77	1.56	0.11	0.093
$T_2 \times G_2$	3.36	3.87	1.99	0.12	0.098
$T_3 \times G_2$	3.01	3.56	1.85	0.11	0.095
$T_4 \times G_2$	4.60	4.06	2.16	0.13	0.104
$T_5 \times G_2$	4.75	4.45	2.40	0.14	0.112
$T_1 \times G_3$	2.51	1.63	1.22	0.09	0.083
$T_2 \times G_3$	3.05	2.22	1.59	0.11	0.091
$T_3 \times G_3$	2.86	2.26	1.40	0.11	0.087
$T_4 \times G_3$	4.43	2.47	1.67	0.12	0.096
$T_5 \times G_3$	4.51	3.27	1.75	0.12	0.107
LSD (0.5)	0.22	0.16	0.12	NS	0.003
CV (%)	5.86	5.22	6.52	5.11	2.77

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).; G_1= BARI Masur-1, G_2= BARI Masur-7 and G_3= BD-3818

Table 7 shows that interaction effect of fertilizer management practices and genotype, the highest number of pods plant^{-1} (98.6) was in $T_5 \times G_2$ treatment combination and the lowest number of pods plant^{-1} (62.5) was in control × BARI Masur-1. Number of seeds plant^{-1} did not influence with interaction effect of fertilizer management practices and genotype. The highest thousand seed weight (22.0 g) was obtained from $T_5 \times G_2$ treatment combination. Statistically identical results were also found in $T_4 \times G_2$ treatment combination and inoculums × BARI Masur-7, whereas the lowest (18.2 g) was in control × BARI Masur-1 (Table 7). The interaction effect of fertilizer management and genotype on the incidence of foot rot and stemphylium blight was significant where the maximum incidence of foot rot (6.93%) and stemphylium blight (4.33) was in control × BARI Masur-1.

The minimum incidence of foot rot (1.16%) and stemphylium blight (0.33) was in $T_5 \times G_2$ treatment combination (Table 7).

Table 7. Interaction effect of fertilizer management practices (T) × genotype (G) on the number of pods plant^{-1}, number of seeds pod^{-1}, thousand seed weight, and incidence of foot rot and *Stemphylium* blight of lentil

Treatment (T) × Genotype (G)	Number of pods plant^{-1}	Number of seeds pod^{-1}	Thousand seed weight (g)	Incidence foot rot (%)	*Stemphylium* blight (0-5 scale)
$T_1 \times G_1$	62.5	1.62	18.2	6.93	4.33
$T_2 \times G_1$	76.5	1.71	18.4	4.26	3.16
$T_3 \times G_1$	68.7	1.70	18.3	6.08	3.50
$T_4 \times G_1$	82.3	1.74	18.5	4.83	2.66
$T_5 \times G_1$	86.2	1.78	18.6	3.11	2.00
$T_1 \times G_2$	78.7	1.71	21.3	3.82	1.66
$T_2 \times G_2$	87.8	1.84	21.8	2.93	1.00
$T_3 \times G_2$	84.0	1.79	21.6	3.01	1.16
$T_4 \times G_2$	92.1	1.86	21.9	2.39	0.83
$T_5 \times G_2$	98.6	1.92	22.0	1.16	0.33
$T_1 \times G_3$	67.1	1.69	20.3	6.14	2.50
$T_2 \times G_3$	81.5	1.79	20.9	4.16	1.50
$T_3 \times G_3$	75.2	1.73	20.3	4.13	2.33
$T_4 \times G_3$	87.6	1.84	21.1	2.83	1.16
$T_5 \times G_3$	92.8	1.85	21.4	2.50	1.00
LSD (0.05)	1.69	NS	0.20	0.86	0.43
CV (%)	1.78	3.81	0.85	18.9	19.2

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed). G_1= BARI Masur-1, G_2= BARI Masur-7 and G_3= BD-3818.

Table 8 clearly demonstrates the significant impact of the interaction between fertilizer management practices and genotype on the yields of lentil. The highest seed yield (1636 kg ha^{-1}) was achieved with the $T_5 \times G_2$ treatment combination and the lowest (909 kg ha^{-1}) was in control × BARI Masur-1. Significantly the highest stover yield (1851 kg ha^{-1}) was in $T_5 \times G_2$ treatment combination, while the lowest (1258 kg ha^{-1}) from the control × BARI Masur-1 (Table 8). On the other hand, the highest biological yield (3488 kg ha^{-1}) was found in $T_5 \times G_2$ treatment combination and the lowest (2166 kg ha^{-1}) was in control × BARI Masur-1. The highest harvest index (46.9%) was in $T_5 \times G_2$ treatment combination and the lowest (42.0%) was in control × BARI Masur-1 (Table 8). The consistent superiority of the $T_5 \times G_2$ treatment combination across all yield parameters (seed yield, stover yield, biological yield, and harvest index) strongly indicates that integrating 50% of the recommended inorganic fertilizer with *Rhizobium* inoculum, specifically with the BARI Masur-7 genotype, creates an optimal environment for maximizing lentil productivity. This outcome is likely a culmination of the positive effects observed in earlier growth stages, such as increased primary branches and higher fresh and dry leaf weights, which collectively contribute to more robust plant development and ultimately, higher yields. The significant increase in harvest index in the $T_5 \times G_2$ treatment is particularly remarkable. A higher harvest index signifies a greater proportion of the total biomass being converted into economically valuable seed yield. This suggests that *Rhizobium* not only enhances overall biomass but also plays a role in optimizing the partitioning of resources towards seed development.

Table 8. Interaction effect of fertilizer management practices (T) × genotype (G) on seed yield, stover yield, biological yield, and harvest index of lentil

Treatment (T) × Genotype (G)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
$T_1 \times G_1$	909	1258	2166	42.0
$T_2 \times G_1$	1152	1483	2640	43.6
$T_3 \times G_1$	1072	1407	2479	43.2
$T_4 \times G_1$	1249	1536	2785	44.8
$T_5 \times G_1$	1325	1607	2931	45.2
$T_1 \times G_2$	1157	1433	2586	44.8
$T_2 \times G_2$	1451	1699	3153	46.0
$T_3 \times G_2$	1404	1665	3069	45.7
$T_4 \times G_2$	1537	1757	3294	46.7
$T_5 \times G_2$	1636	1851	3488	46.9
$T_1 \times G_3$	1009	1332	2345	43.0
$T_2 \times G_3$	1354	1683	3039	44.5
$T_3 \times G_3$	1272	1614	2886	44.1
$T_4 \times G_3$	1403	1696	3099	45.3
$T_5 \times G_3$	1442	1704	3146	45.8
LSD (0.05)	30.2	36.6	65.9	0.16
CV (%)	2.00	1.98	1.96	0.31

The means in a column having the different letters is statistically significance at the 5% level using LSD test (least significant difference), CV = coefficient of variation. T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed).G_1= BARI Masur-1, G_2= BARI Masur-7 and G_3= BD-3818.

Cost and return analysis of lentil cultivation by application of combining bio-fertilizer with chemical fertilizers

Regarding the cost and return analysis, the maximum gross return of BDT 100041 ha^{-1} was achieved with the $T_5 \times G_2$ treatment combination. The minimum gross return of BDT 55768 ha^{-1} was observed in the Control × BARI Masur-1 group. For net return, the $T_5 \times G_2$ treatment combination again outperformed others, yielding the highest net return of BDT 73999 ha^{-1} and an impressive benefit-cost ratio of 3.84. Conversely, the Control × BARI Masur-1 treatment combination resulted in the lowest net return of BDT 31568 ha^{-1} and a benefit-cost ratio of 2.30 (Table 9) which is higher than that of Monira *et al*. (2025) where their BCR was 1.17.

Table 9. Cost and return analysis of lentil genotypes influenced by fertilizer management practices × genotypes

Treatment (T) × Genotype	Seed yield (kg	Stover yield (kg	Gross return	Cultivation cost	Net return (BDT ha^{-1})	BCR
$T_1 \times G_1$	909	1258	55768	23600	32168	2.36
$T_2 \times G_1$	1152	1483	70583	23757	46826	2.97
$T_3 \times G_1$	1072	1407	65727	27570	38157	2.38
$T_4 \times G_1$	1249	1536	76446	27727	48719	2.76
$T_5 \times G_1$	1325	1609	81087	26042	55045	3.11
$T_1 \times G_2$	1157	1433	70833	23600	47233	3.00
$T_2 \times G_2$	1451	1699	88769	23757	65012	3.73
$T_3 \times G_2$	1404	1665	85885	27570	58315	3.12
$T_4 \times G_2$	1537	1757	93947	27727	66220	3.39
$T_5 \times G_2$	1636	1851	100041	26042	73999	3.84
$T_1 \times G_3$	1009	1332	61862	23600	38262	2.62
$T_2 \times G_3$	1354	1683	82893	23757	59136	3.48
$T_3 \times G_3$	1272	1614	77914	27570	50344	2.83
$T_4 \times G_3$	1403	1696	85886	27727	58159	3.10
$T_5 \times G_3$	1442	1704	88204	26042	62162	3.39

T_1 = Control (no use of fertilizer), T_2 = *Rhizobium* inoculum (30 g/kg seed), T_3 = Recommended dose of inorganic 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB (FRG, 2012), T_4 = 20-15-25-10-2-1.5 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed) and T_5 = 50% 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum (30 g/kg seed). G_1= BARI Masur-1, G_2= BARI Masur-7 and G_3= BD-3818. **Output price:** Lentil seed= BDT 60 kg^{-1}, and stover = BDT 1.00 kg^{-1}. **Input prices:** Urea= BDT 20 kg^{-1}, Triple super phosphate= BDT 22 kg^{-1}, Muriate of potash= BDT 16 kg^{-1}, Gypsum= BDT 15 kg^{-1}, Zinc sulphate= BDT 1400 kg^{-1}, Boric acid= BDT 1200 kg^{-1}, *Rhizobium* inculum= BDT 150 kg^{-1}, Wage rate= BDT 600 day^{-1}, Ploughing= BDT 1200 $pass^{-1}acre^{-1}$, Provex-200= BDT 300 100^{-g}, Imitaf 20 SL= BDT 265 100^{-ml}, Dithane M-45= BDT 150 100^{-g}, Lentil seed= BDT 100 kg^{-1}. The gross return was calculated on the farm gate price of Barishal district, Bangladesh. BDT is Bangladesh currency or Bangladeshi Taka; 1USD = 82 BDT. BCR: Benefit Cost Ratio.

Conclusion

Based on the comprehensive analysis of morphological and yield attributes, BARI Masur-7 consistently proved to be the superior lentil genotype, exhibiting enhanced growth, higher yield components, and it also displayed lower incidences of foot rot and Stemphylium blight across various fertilizer management practices. The most effective strategy for maximizing lentil yield involved inoculating seeds with Rhizobium bio-fertilizer (30 g kg^{-1} seed) combined with 50% of the recommended inorganic 10-7.5-12.5-5-1-0.75 kg ha^{-1} NPKSZnB + *Rhizobium* inoculum fertilizer. This approach not only optimized production but also achieved a significant 54.7% reduction in chemical fertilizer costs. Therefore, it can be conclusively stated that the integrated use of Rhizobium bio-fertilizer with a reduced amount of chemical fertilizer offers a highly effective, sustainable, and economically beneficial package for boosting lentil production in the Ganges Tidal Floodplain soil.

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