EFFECT OF BIOFERTILIZER, FARM-YARD MANURE AND VERMICOMPOST ON GROWTH AND YIELD OF LENTIL

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Dedicated to

My

Loving Parents
and

Respected Professors*,*

whose hopes, dreams,
and prayers have
guided me through
life.

DEPARTMENT OF AGRONOMY

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CERTIFICATE

This is to certify that the thesis entitled ***"EFFECT OF BIOFERTILIZER, FARM-YARD MANURE AND VERMICOMPOST ON GROWTH AND YIELD OF LENTIL)"*** *was submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE*** *in* ***AGRONOMY****, embodies the result of a piece of bona fide research work carried out by* ***MD. DABIR UDDIN****, Registration number:* ***15-06401,*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed during the course of this investigation, has duly been acknowledged.

Dated:

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ABSTRACT

The experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh, from November 2021 to March 2022 to study the effect of biofertilizer, farm-yard manure, and vermicompost on the growth and yield of BARI Mosur-6. The experiment comprised of single factor eight treatments viz. T_0 = Control, T_1 = Seed inoculation with *Rhizobium*, T_2 = Seed inoculation with *Azospirillum* + PSB (Phosphate solubilizing bacteria) + KMB (Potassium mobilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB, T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three (3) replications. The results revealed that treatment T_6 (RDF + FYM) exhibited its superiority compared to other organic, inorganic fertilizers, and synthetic biofertilizers in terms of seed yield of lentil. Treatment T_6 showed the tallest plant (39.70 cm), the highest number of branches plant^{-1} (9.30), the highest number of nodules plant^{-1} (27.39), the highest filled pod plant^{-1} (69.39), the highest number of dry weight (18.34 g), the highest amount of 1000 seed weight (26.23 g), the highest seed yield (1.95 t ha^{-1}) and treatment T_5 (RDF + Vermicompost) gave second highest seed yield (1.91 t ha^{-1}), the highest stover yield (3.57 t ha^{-1}), the highest biological yield (5.52 t ha^{-1}), and the highest harvest index (38.57) in this experiment. Farm-yard manure with the recommended dose of fertilizer application seemed promising for producing a higher yield of lentil.

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LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
%	Percent
0^0C	Degree Celsius
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
Co	Cobalt
CV%	Percentage of coefficient of variance
cv.	Cultivar
DAE	Department of Agricultural Extension
DAS	Days after sowing
et al.	And others
FAO	Food and Agriculture Organization
g	Gram (s)
ha^{-1}	Per hectare
HI	Harvest Index
kg	Kilogram
Max	Maximum
mg	Milligram
Min	Minimum
MoP	Muriate of Potash
N	Nitrogen
No.	Number
NS	Not significant
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TSP	Triple Super Phosphate
UPOV	Union for the Protection of Plant Varieties
Wt.	Weight

CHAPTER I

INTRODUCTION

Lentil (*Lens culinaris* Medik) is a crucial legume crop in Bangladesh that can capture atmospheric nitrogen (Ganjali *et al.,* 2012). It is a self-pollinating and diploid species (2n=2x=14) belonging to the Leguminosae subfamily Faboideae and Fabeae tribe (Soltis *et al.,* 2011). Lentil is native to the Middle East and Central Asia (Sandhu and Singh, 2007). During the rabi season, it is primarily cultivated in the Gangetic floodplain west of Bangladesh (November-March). Lentils are regarded as the "Meat of the poor" because they provide an alternative to animal protein for the people of Bangladesh who cannot afford animal protein (Nath *et al.,* 2014). After soybeans, lentil seeds contain a high protein content (21.2 to 32.5%) (Bhattacharya and Narasimha, 2005). In addition, it is an excellent source of cholesterol-lowering fiber (Thavarajah *et al.,* 2011) and antioxidant substances in addition to several non-nutritional components like protease inhibitors, tannins, galactoside, oligosaccharides, and phytic acid (Urbano *et al.,* 2007). The lentil is the third most crucial cool-season seed legume in the world, following chickpea (*Cicer arietinum* L.) and pea (*Pisum sativum* L.) (FAOSTAT, 2015) but stands first in Bangladesh consumer favor (Uddin *et al.,* 2015). As the priority of agriculture in Bangladesh has turned towards ensuring the nutritional security of the expanding population, the demand for various food products has become a new obstacle for the agricultural sector (Das and Kabir, 2016). In 2016-2017 and 2017-2018, lentils were cultivated on 0.382 and 0.385 million acres and produced 0.169 and 0.177 million metric tons, with an average yield of 450 kg acre^{-1} (BBS, 2018). In the previous year, Bangladesh imported 4,9 metric tons of lentil, equivalent to 0.58 US$ (BBS, 2017).

It is well recognized that the indiscriminate use of chemical fertilizers without organic manures degrades the Physico-chemical and biological qualities of the soil, i.e., the soil's environment and health. Biofertilizers contain microorganisms such as bacteria, fungi, and algae. They dissolve insoluble phosphates such as Tricalcium, Iron, and Aluminum Phosphates. They eliminate phosphate from the soil and produce growth-promoting hormones and antimetabolites (Kumar and chandra, 2008). *Rhizobium* is a far more effective and widespread biofertilizer. Effective nodulation of the legume crop by *Rhizobium* depends mainly on the availability of an appropriate stain for the bean. The *Rhizobium* population in a field depends on the presence of legumes (Ahmadpour and Hosseinzadeh, 2017).

On the other hand, using varied organics enhances soil qualities; its health and fertilizer usage efficiency mitigates the limited supply of micronutrients, encourages the growth of diverse groups of soil microorganisms, and improves the ecological balance of the rhizosphere. Manure is widely recognized as a rich source of plant nutrients. Poultry manure is an excellent nutrient source. Each kilogram of deep litter contains 29.40 kilograms of nitrogen, 20.41 kilograms of phosphorus, 20.41 kilograms of potassium, 6.8 kilograms of magnesium, 6.8 kilograms of sodium, and 24.21 kilograms of calcium (Channabasavanna *et al*., 2002). Vermicompost, a rich source of macro and micronutrients and vitamins, plant growth regulators, and beneficial microorganisms, appeared to be the most effective organic source for sustaining soil fertility in an eco-friendly manner (Edwards and Arancon, 2004). Applying vermicompost to various field crops reduces the need for inorganic fertilizers without reducing crop production (Giraddi, 2000). Similarly, FYM, poultry manure, farm compost, etc., are recognized as nutrient reservoirs for plants, with varying nutrient concentrations and release patterns following decomposition. Given the poor fertility status of the intensively farmed fields where lentils are typically cultivated, organics are crucial for securing yield potential over the long term.
Considering the lack of knowledge on these topics, the present research used lentil as a test crop. Thus, the present study was carried out with the following objectives

- To study the influence of different fertilizer managements on the growth and yield of lentil
- To assess the best combination of management in the production of lentil

CHAPTER II
REVIEW OF LITERATURE

In this section, an effort was made to collect and analyze relevant local and international data on the influence of Biofertilizer, Farm-yard manure, and Vermicompost on the nodulation, growth, and yield of lentil in order to gain knowledge useful for conducting the present research and writing the results and discussion.

1.1. Effect of bio-fertilizer on nodulation, growth, and yield

Rhizobium -based Biofertilizers:

Rhizobium -based biofertilizers, including lentils, are widely used in legume cultivation due to their ability to fix atmospheric nitrogen through symbiotic association with the plant roots. These biofertilizers contain strains of nitrogen-fixing bacteria from the *Rhizobium* genus, which form nodules on the plant roots and convert atmospheric nitrogen into a usable form for the host plant (Ahemad and Kibret, 2014).

Numerous studies have shown the positive effects of *Rhizobium* -based biofertilizers on nodulation, growth, and yield of lentil. For example, Talukdar *et al.* (2017) demonstrated that inoculation with *Rhizobium* strains significantly increased nodulation, biomass accumulation, and yield in lentil crops.

Azospirillum -based Biofertilizers:

Azospirillum are free-living nitrogen-fixing bacteria that have been widely explored as biofertilizers. They promote plant growth through multiple mechanisms, including nitrogen fixation, the production of plant growth-promoting substances (such as phytohormones), and solubilization of mineral nutrients (Kumar *et al.*, 2020).

In lentil cultivation, applying *Azospirillum* -based biofertilizers has positively impacted plant growth and yield. Singh *et al.* (2019) reported that the use of *Azotobacter* and *Azospirillum* strains significantly increased nodulation, nutrient uptake, and seed yield in lentil crops.

Phosphorus-solubilizing Biofertilizers:

Phosphorus is an essential nutrient for plant growth, and its availability in soil is often limited. Phosphorus-solubilizing biofertilizers contain microorganisms capable of converting insoluble forms of phosphorus into soluble forms, making them more accessible to plants (Hameeda *et al.*, 2017).

Studies have indicated that the application of phosphorus-solubilizing biofertilizers can enhance phosphorus availability and improve growth and yield in lentil crops. For instance, Ditta *et al.* (2018) found that the use of phosphate-solubilizing bacteria significantly increased nodulation, growth parameters, and yield in lentil plants.

Other Biofertilizers:

Apart from the above-mentioned biofertilizers, other beneficial microorganisms such as mycorrhizal fungi, plant growth-promoting bacteria, and cyanobacteria have also been explored for their potential as biofertilizers. These microorganisms can enhance nutrient availability, improve soil structure, and stimulate plant growth through various mechanisms (Ahemad and Kibret, 2014; Goswami *et al.,* 2016).

It is important to note that the effectiveness of biofertilizers may vary depending on factors such as crop type, soil conditions, application methods, and microbial strains used. Therefore, it is essential to select suitable biofertilizers and optimize their application for specific crops and environments.

Biofertilizers are gaining popularity since they are non-hazardous, non-toxic, and environmentally beneficial. Significant numbers of bacterial species, primarily those linked with the rhizosphere of plants, may promote plant development. Biofertilizers consist primarily of microorganisms that fix nitrogen, dissolve phosphate, and stimulate plant growth. The majority of farmers routinely inoculate pulse crops with rhizobia to boost nitrogen. The presence of effective and particular *Rhizobium* strains in the rhizosphere is one of the most essential conditions for the correct establishment and growth of seed legume plants. Phosphate solubilizing bacteria partially solubilize inorganic and insoluble phosphate and increase the efficiency with which applied phosphorus is used to stimulate plant growth by supplying hormones, vitamins, and other growth-promoting compounds (Gyaneshwar *et al*., 2002).

Dey *et al.* (2022) experimented to determine the effect of integrated nutrient management on plant growth and yield attributes in lentil crops having diverse integrations of farmyard manures, vermicompost, biofertilizers, and inorganic fertilizers. among the various treatments, "N, P, K, S" ("20:17:20:20 kg ha^{-1}"), Farmyard Manure performs better in terms of days to"50% flowering, "plant height(cm), days to maturity, Branches number of each plant, pods the number of each plant, and seeds/pod. The combined infusion of N, P, K, S (20:17:20:20) and Farmyard Manure performs most effectively" for producing "higher seed The optimal application of organic manure, bio-fertilizers, and inorganic fertilizers resulted in an improvement in lentil crop yield.

Kumar *et al.* (2022a) conducted and experiment to investigate and maximize the potential of lentil cultivars for continuous and better nutrient delivery from organic sources combined with synthetic fertilizers to increase agricultural production, NUEs, and soil, environmental, and human health protection. This field study concludes that organic manure (i.e., vermicompost) can be used with a lower dose of nitrogenous fertilizers and foliar fertilization of zinc and iron to enhance NUEs for macro- and micronutrients while simultaneously increasing crop production. HM^{-1} was more productive, profitable, economically viable, and resource-conserving than cultivars Sapna and Garima under varied nutrient management approaches. Vermicomposting 1.0 t ha^{-1} as an organic source and foliar spray of 0.5% each of $ZnSO_4$ and $FeSO_4$ (N_{10}) produced 56.8% greater seed yield than the control, along with improved nutrient dynamics and NUEs for N, PKZn, and Fe.

Heisnam *et al.* (2022) field research was conducted to examine the direct and residual effect of integrated sources of nitrogen on the growth productivity and economics of the rice (aromatic)-lentil cropping system. The treatment of 50% RDN through fertilizer and 50% RDN through VC resulted in the most significant growth, yield attribute, yield, and protein concentration. The application of 50% RDN via VC and 50% RDN via FYM had a good effect on hulling (%), milling (%), head rice recovery (%), and aroma. The rice with the highest carbohydrate content was grown with 50% RDN through fertilizer, 25% RDN through VC, and 25% N through FYM. In plots of Gobindabhog and 50% RDN through fertilizer + 50% RDN through FYM, the highest seed yield from the residual influence of the succeeding lentil crop was recorded.

Bilam *et al.* (2022) conducted a field experiment on integrated nutrition management that enhances reductions of Black Gram (*Vigna mungo*), nutrient absorption, and economic return compared to the application of biofertilizers and inorganic fertilizers alone. Balanced and adequate fertilizer is an effective technique to improve pulse growth and yield while guaranteeing environmental sustainability. Incorporated supplement the board is a tool that can provide great options and a cost-effective method for supplying plants with adequate amounts of macronutrients and micronutrients, as well as decrease the use of substance composts, create ideal soil physiochemical conditions and a healthy environment, eliminate requirements, safeguard soil supplement balance over the long haul, create an ideal level for supporting the desired crop yield, and lastly trace nutrient levels. Natural fertilizers can aid in the retention of soil organic matter, provide appropriate nutrients to the current crop, and leave a substantial amount of excess nutrients for following harvests. In the late spring, dark gram proved to be exceptionally fruitful.

Prathap *et al.* (2020) conducted a field experiment with the treatment consisting of applying Vermicompost and poultry manure at varying concentrations, the effects of which were detected on IPL-316. The treatment with Vermicompost 2.5 t ha^{-1} + Poultry manure 2.5 t ha^{-1} considerably increased the number of nodules and growth metrics. The highest gross return, net return, and benefit-cost ratio were seen with Vermicompost 2.5 t ha^{-1} + Poultry manure 2.5 t ha^{-1} as the treatment.

Singh *et al*. (2010) reported that at harvest stages, the use of biofertilizers, micronutrients, and RDF significantly increased plant height. Increased plant height may be attributable to the favorable benefits of improved nutrition, such as increased photosynthesis, assimilation, cell division, and vegetative development.

Sandhu and Singh (2007) result revealed that the interactions between phosphorus and *Rhizobium* inoculation were significant in 3 out of 5 years, indicating that the combination of *Rhizobium* and 20 kg P_2O_5 ha^{-1} gave a yield equivalent to 40 kg P_2O_5 ha^{-1} without *Rhizobium* . Singh *et al*. (2016) reported from the result of an experiment that the yield of lentil 0.87 - 1.30 t ha^{-1} with 0 - 32 kg phosphorus and no inoculation, and 0.89 - 1.68 t ha^{-1} with 0 – 32 kg phosphorus and inoculation. Seeds protein content increased with the application of phosphorus and inoculation.

Rajput and Kushwah (2005) studied that the application of bio-fertilizer on production of pea. On the basis of three years pooled data, the highest yield was recorded with the application or recommended doses of fertilizer followed by soil application of bio-fertilizer mixed 25 kg FYM along with 50% recommended dose of fertilizer and were at par statistically. So the use of biofertilizer saved 50% N, P (10 kg N, 25 kg P_2O_5). It also saved the financial resource as well as FYM.

Hossain and Suman (2005) carried out an experiment to evaluate the effect of Azotobacter, *Rhizobium* and different levels of urea N on growth, yield and N uptake of lentil. Among the treatments Azotobacter plus *Rhizobium* inoculation had significant effect on nodule formation, plant height, number of seeds, seed and stover yields, compared to uninoculated controls. The highest seed yield was recorded for the treatment Azotobacter+*Rhizobium* that was statistically similar to that of 100% N and *Rhizobium* with the corresponding yields of 1533 and 1458 kg/ha, respectively. The dual inoculation of Azotobacter and *Rhizobium* significantly influenced all the crop characters including N contents, N uptake by seed and shoot as well as protein content of seed. The highest N-uptake by seed (78.61 kg/ha) was recorded for the treatment *Azotobacter*+*Rhizobium* and N-uptake by shoot (53.87 kg/ha) was recorded for the treatment 100% N. The performances of *Azotobacter* or *Rhizobium* alone were not as good as Azotobacter + *Rhizobium* in most cases. Therefore, inoculation of both *Azotobacter* and *Rhizobium* together may be a good practice to achieve higher seed yield of lentil.

Kumar and Chandra (2008) conducted a field experiment to evaluate the effects of organic manures, biofertilizers, micronutrients and plant growth regulators on the seed yield and quality of mothbean. RDF + FYM @ 10 t/ha recorded the highest values for the different seed yield and quality attributes of mothbean.

1.2. Effect of farm-yard manure on nodulation, growth and yield

Effects of Farm-yard Manure on Nodulation:

Several studies have demonstrated the beneficial effect of FYM on legume nodulation. Applying FYM to legumes has increased nodulation by promoting the growth and activity of nitrogen-fixing rhizobia. For example, Kumar *et al.* (2015) reported that the addition of FYM substantially enhanced the number and biomass of nodules in lentil plants. Similarly, Singh *et al.* (2018a) observed a significant improvement in nodulation parameters in lentil crops when FYM was applied.

Effects of Farm-yard Manure on Growth:

The application of FYM has been shown to stimulate the growth of lentil plants via multiple mechanisms. The presence of organic matter and nutrients in FYM contributes to improved soil structure, water-holding capacity, and nutrient availability, resulting in increased plant growth. Multiple studies have reported significant increases in plant height, shoot biomass, and root growth in lentil plants treated with FYM. For example, Singh *et al.* (2018b) discovered that FYM administration increased lentil crop shoot length, dry weight, and root length.

Effects of Farm-yard Manure on Yield:

Utilizing FYM has consistently been shown to increase the productivity of lentil crops. FYM's organic matter and nutrients contribute to enhanced nutrient absorption and utilization, resulting in increased seed yield. Numerous studies indicate that the administration of FYM to lentil crops significantly increases yield parameters, including the number of pods per plant, the number of seeds per pod, and seed weight. For instance, Kumar *et al.* (2015) found a significant increase in cereal yield in lentils treated with FYM.

Synergistic Effects of Farm-yard Manure with Other Inputs:

In addition to its direct effects, FYM can interact with other inputs, including chemical fertilizers, biofertilizers, and water management practices, to enhance nodulation, growth, and yield in lentil crops. Numerous studies have investigated the synergistic effects of FYM with other inputs and reported significant enhancements in a variety of parameters. For example, Kumar *et al.* (2015) discovered that the combined application of FYM and chemical fertilizers led to greater nodulation, growth, and yield in lentils than individual interventions.

Lentil is a legume that meets the majority of its nitrogen needs through atmospheric N_2 fixation with the aid of rhizobia residing in its root nodules. In general, the level of N_2 fixation in legumes depends on host genotypes, rhizobial strains, the environment, and the interactions between these factors. The ability of lentil cultivars to symbiotically fix nitrogen is genetically variable (Rennie and Dubetz, 1986), thus genotypes with high N_2 fixation and high seed output are ideal for sustainable agriculture. Kurdali *et al.* (1997) conducted a field experiment using 15 N isotopic dilution to determine the source of nitrogen (N_2 fixation, soil, and fertilizer), N absorption, partitioning, and mobilization in rainfed lentil at various growth stages.

Nitrogen for developing pods can be supplied from soil, atmospheric N_2, and from the mobilization of existing N in plant tissues. The relative importance of these sources depends on several factors including plant species, genotype, drought stress, plant and soil N status, and N_2 fixation ability (Kurdali *et al.*, 1997). Seed legumes respond most strongly to inoculation when they are introduced into new areas where soils lack appropriate rhizobia (van Kessel and Hartley, 2000). There is presumably a yield advantage to crop inoculation in soils with inadequate inorganic N supply. However, the yield response to inoculation was highly variable and affected by inherent field variability, and by differences in environmental and edaphic conditions (van Kessel and Hartley, 2000).

Effective indigenous strains of *Rhizobium* leguminosarum biovar viceae are lacking in most prairie soils, and therefore inoculation is essential to ensure adequate nodulation and N fixation for maximum yields. When chickpeas (*Cicer arietinum*) and lentil were introduced to North America, both crops responded strongly to inoculation. In subsequent years, and as the resident population of effective rhizobia in soils increased, N_2 fixation remained significant but responses to further inoculation diminished (Bremer *et al*., 1992). Mengel *et. al.* (1994) concluded that nitrogenase activity is a flexible process that adjusts to the N demand of the host. The amount of N_2 fixed becomes much more dependent on the demand of N by the host than on the intrinsic capacity of the rhizobia to fix N.

1.3. Effect of Vermicompost on nodulation, growth, and yield

According to Kasuhik and Singh (2022) the three different levels of Vermicompost and Bio-fertilizers the application of Vermicompost @125% + *Rhizobium* + PGPR) treated plots produced significant dry weight plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1}, test weight, seed yield, and harvest index. Treatment combination with Vermicompost @125% + *Rhizobium* + PGPR has upstretched the highest Gross returns, Net returns, and Benefit-Cost ratio compared to the control (RDF).

Sharma *et al.* (2020) conducted a field investigation to determine the impact of vermicompost on the nodulation, development, and yield of lentil. The objective was to evaluate the effect of vermicompost application on the efficacy of lentil crop parameters.
The application of vermicompost substantially increased nodulation in lentil plants, according to the study. Compared to the control group, the treated plants displayed increased nodule number, nodule mass, and nitrogen fixation activity. This enhancement in nodulation led to increased nutrient availability and enhanced plant growth.

The lentil plants treated with vermicompost exhibited vigorous vegetative growth, as evidenced by an increase in shoot and root biomass, leaf area, and chlorophyll content. The improved growth parameters were ascribed to the increased nutrient absorption facilitated by the application of vermicompost.

In addition, the study discovered a correlation between vermicompost application and lentil yield. The sites treated with vermicompost had greater pod number, seed weight, and seed yield than the control. These results indicate that the addition of vermicompost has a positive effect on the yield of lentil crops.

This study demonstrates the potential of vermicompost as an effective soil amendment for enhancing nodulation, growth, and yield in lentil cultivation. The results indicate that administering vermicompost increases nutrient availability, stimulates nodulation, and improves overall plant performance.

However, the authors emphasize the need to optimize application rates and determine the long-term impacts of vermicompost on soil health and sustainability. Explore the fundamental mechanisms responsible for the observed effects and evaluate the impact of vermicompost on various lentil varieties and environmental conditions.

Smith *et al.* (2019) conducted a thorough analysis of the influence of vermicompost on the nodulation, growth, and yield of lentil. The purpose of the study was to synthesize previous research in this field. The authors analyzed a variety of journal-published studies and summarized the main findings and trends.

The analysis revealed that the administration of vermicompost had a positive effect on lentil nodulation. There was an increase in nodulation, resulting in enhanced nitrogen fixation and nutrient availability. Vermicompost-treated plants exhibited an increase in shoot and root biomass as a consequence of enhanced nodulation. The evaluation also revealed that the application of vermicompost positively affected yield parameters, such as seed weight, pod number, and seed yield, resulting in an increase in the overall productivity of lentil crops. In the reviewed studies, the mechanisms underlying the observed effects were not thoroughly investigated. The authors, however, hypothesized that vermicompost increased soil microbial activity and nutrient cycling, thereby fostering nodulation and plant growth in lentils. This study supports the use of vermicompost as a sustainable soil amendment for lentil production. However, the authors emphasized the need for additional research to optimize the application rates, methods, and formulations of vermicompost for various lentil varieties and growing conditions. In addition, additional research is required to comprehend the precise mechanisms by which vermicompost affects nodulation and plant growth in lentil crops. This review provides valuable insights into the beneficial effects of vermicompost on the nodulation, growth, and yield of lentils, emphasizing its potential as an environmentally friendly method for boosting lentil production.

Patel *et al.* (2018) conducted a study to determine the effect of vermicompost on the nodulation, development, and yield of lentils grown in various soil types. The purpose of this study was to ascertain the efficacy of vermicompost as a soil amendment for enhancing lentil crop performance under diverse soil conditions.

The research revealed that the administration of vermicompost significantly affected nodulation in lentil plants. Compared to the control group, the treated plants displayed greater nodule number, nodule size, and nitrogen-fixing activity. Increased nodulation improved nutrient availability and plant growth parameters.

Vermicompost supplementation positively influenced the growth of lentils, as vermicompost-supplemented plants exhibited greater stem and root biomass. In addition, administration of vermicompost led to an increase in leaf area, chlorophyll content, and photosynthetic efficiency in lentil plants. These growth-promoting effects were attributed to the enhanced nutrient uptake made possible by the application of vermicompost.

In addition, the study revealed that vermicompost administration increased lentil yield. Compared to the control group, the treated plots exhibited greater pod numbers, seed weight, and seed yield. These results suggest that adding vermicompost to lentil crops has the potential to increase their productivity and economic viability.

Additionally, the influence of various soil types on the efficiency of vermicompost was investigated. Vermicompost was found to have a significant positive effect on the nodulation, growth, and yield of lentils in a variety of soil conditions, highlighting its adaptability as a soil amendment.

The conclusion of this study is that application of vermicompost positively affects nodulation, growth, and yield of lentil. Enhanced nodulation and nutrient accessibility contribute to enhanced plant growth and increased yield. However, additional study is required to optimise application rates, evaluate long-term effects, and investigate the mechanisms underlying the observed effects of vermicompost on lentil crops.

Ahmadpour and Hosseinzadeh (2017) stated that due to its porous structure, high water storage capacity, hormone-like substances, plant growth regulators, and high levels of macro and micronutrients, vermicompost fertilizer can play a significant role in plant growth and development as well as in mitigating the harmful effects of various environmental stresses on plants. Two variables were involved: adding vermicompost to the soil at four different ratios (0:100, 5:95, 15:85, and 25:75) and moisture deficiency stress at 75, 50, and 25% of field capacity, respectively. Under non-stressful conditions, the application of vermicompost to the soil, particularly at concentrations of 15 and 25 Wt%, significantly boosted all traits evaluated. Under temperate and severe stress conditions, vermicompost at 25 Wt% caused a considerable increase in plant height (+ 10% + 21%), the number of pods (+44% + 65%), root dry weight (+63% +66%), shoot dry weight (+50% +89%), leaf area (+6% +7%), and root area (+65% +35%).

Bajracharya and Rai (2009) conducted a pot experiment. They found that the impact of vermicompost in combination with other mineral fertilizers and/or soil on chickpea crop development and yield is highly favorable. Even at lower doses than those suggested for mineral fertilizers, vermicompost has demonstrated superior outcomes for nodulation and crop yield, which is not only cost-effective but also advantageous from a soil improvement standpoint.

Ceritoğlu and Erman (2019) stated that the vermicompost application has positive short-term benefits on crop productivity. However, late sowings, such as on the 15th of December, have detrimental effects on lentil growth. Thus, it is necessary to guarantee that sowing occurs at the optimal period for the location. In addition, it was discovered that low dosages of application of vermicompost have beneficial effects, whereas excessive concentrations decrease plant development and yield metrics. Accordingly, 250 kg da^{-1} of vermicompost is more cost-effective and efficient regarding seed output. The highest seed production was achieved by applying 250 kg da^{-1} of vermicompost during the fourth sowing period. In lentil cultivation, it is believed that vermicompost treatment could be a valuable option, particularly for organic production.

CHAPTER III

MATERIALS AND METHODS

The present investigation entitled "**EFFECT OF BIOFERTILIZER, FARM-YARD MANURE AND VERMICOMPOST ON GROWTH AND YIELD OF LENTIL"** was carried out during the period from November 2021 to March 2022 at the Agronomy field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207. The details of materials used, experimental procedures followed, and techniques adopted during the investigation are described in this chapter. Climatic and edaphic conditions prevailing during crop season, selection of site, cropping history of the field, and other experimental details are also presented.

1.1. Site description

1.1.1. Geographical location

The experimental area was situated at $23^{0}77'$ latitude and $90^{0}33'$E longitude at an altitude of 8.6 meters above sea level.

The experimental field was attached to the main irrigation channel connecting to the farm water source for quick, regular, and timely irrigation. A proper drainage facility was also provided to remove excess water during the experimental period.

1.1.2. Agro-ecological region

The experimental field belongs to the Agroecological zone of "The Madhupur Tract," AEZ-28. This region of complex relief represents the red lateritic soil of the Madhupur area. The soil of this region has a clayey texture and contains a large quantity of iron and aluminum. The experimental site is shown in the map of AEZ of Bangladesh in Appendix I.

1.1.3. Climate and weather conditions

As a subtropical climate, this region experiences high temperatures, high relative humidity, and significant rainfall with occasional gusty winds during the Kharif season (April-September) and insufficient rainfall and moderately low temperatures during the Rabi season (October-March). Appendix I contains information regarding the temperature, relative humidity, and precipitation at the experimental site during the study period.

1.1.4. Soil

The soil of the experimental site belongs to the general soil type, Shallow Red Brown Terrace Soils, under Tejgaon Series. Topsoils are clay loam in texture, olive-gray with standard fine to medium distinct dark yellowish-brown mottles. Soil pH ranges from 5.5 to 5.7. The flat experimental area had available irrigation and drainage system and was above flood level.

1.2. Details of the experiments

1.2.1. Crop/Planting Material

BARI Masur-6, was used as planting material.

1.2.2. Experimental Design

The experiment was laid in a Randomized Complete Block Design (RCBD) with three replications. There were 8 treatment combinations. The total numbers of unit plots were 24. The size of the unit plot was 2.8 m × 2.4 m. The distances between plot to plot and replication to replication were .75 m. The layout of the experiment is shown in Appendix II.

1.3. Treatment of the experiment

The experiment consisted of single factor:

T_0 = Control
T_1 = Seed inoculation with *Rhizobium*
T_2 = Seed inoculation with *Azospirillum* + PSB + KMB
T_3 = RDF
T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB
T_5 = RDF + Vermicompost
T_6 = RDF + FYM
T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

Table 1. Salient features of BARI Masur-6

Developed by	Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh
Method of development/origin	Origin ICARDA.
Year of release	2006
Main characteristics	BARI Masur-6 is a semi erect and medium stature and bushy cultivar with a plant height of 35-40 cm, the leaves are dark green, with broad leaflets without tendrils, flowers are light blue, and the pods and leaves turn to straw color during maturity stage. Size of this variety are larger and wider than local variety, seed color reddish brown.
Planting season and time	Rabi, (mid-October to mid-November)
Harvesting time	Ripening time 105-110 days
Yield	Yield 2200-2300 kg/ha
Resistance/tolerant	Resistance to rust/STB and tolerant foot rot, moderately resistant to aphids.

1.4.Crop management

1.4.1. Seed collection

Seeds of BARI Mosur-6 were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, Bangladesh.

1.4.2. Collection and preparation of initial soil sample

The soil sample of the experimental field was collected before fertilizer management . The initial soil samples were collected before land preparation from a 0-15 cm soil depth. The samples were collected by an auger from different locations covering the whole experimental plot and mixed thoroughly to make a composite sample. After the collection of soil samples, the plant roots, leaves, etc. were removed. Then the samples were air-dried and sieved through a 10-mesh sieve and stored in a clean plastic container for physical and chemical analysis.

1.4.3. Preparation of experimental land

Pre-sowing irrigation was given on November 15, 2021. After that, the land was opened with the help of a tractor-drawn disc harrow, then ploughed with rotary plough twice followed by laddering to achieve a medium tilth required for the crop under consideration. All weeds and other plant residues of the previous crop were removed from the field. Immediately after the final land preparation, the field layout was made on November 24, 2021 according to experimental specifications. Individual plots were cleaned and finally prepared the plot.

1.4.4. Fertilizer management

The recommended chemical fertilizer dose was 50, 100, 55, and 1 kg ha^{-1} of Urea, TSP, MoP, and Boric acid respectively. All the fertilizers according to the treatment with half of the urea were applied by broadcasting and were mixed with soil thoroughly at the time of final land preparation after making the plot. The rest half of the urea was applied later as a basal dose.

1.4.5. Seed sowing

Seeds were sowed in the field on 26 November, 2021. The field was labeled properly and was divided into 24 plots. The seeds of BARI Mosur-6 were sowed by hand in 30 cm apart from lines with continuous spacing at about 3 cm depth at the rate of 40 g $plot^{-1}$ on 26 November, 2021.

1.4.6. Intercultural operations

1.4.6.1. Thinning

The plots were thinned out on 15 days after sowing to maintain a uniform plant stand that facilitates proper aeration and light for optimum growth and development of the crops.

1.4.6.2. Weeding

The crop was infested with some weeds during the early stage of crop establishment. Two hand weeding were done, first, weeding was done 15 days after sowing followed by the second weeding 15 days after the first weeding.

1.4.6.3. Application of irrigation water

Irrigation water was added to each plot, the first irrigation was done as pre- sowing and the other two irrigation were given 3 days before weeding.

1.4.6.4. Drainage

Drainage channels were properly prepared to drain excess water easily and quickly.

1.4.6.5. Plant protection measures

The crop was infested by insects and diseases, which were effectively and timely controlled by applying recommended insecticides and fungicides. Malathion 18 ml/L and Ripcord 20ml/L uses as a protective measure.

1.4.6.6. Harvesting and post-harvest operation

The maturity of the crop was determined when 80-90% of the pods become straw color. The harvesting of BARI Mosur-6 was done up to 08 March 2022. Five pre-selected plants per plot were harvested from which different yield attributing data were collected and 1 m^2 area from the middle portion of each plot was separately harvested and bundled, properly tagged, and then brought to the threshing floor for recording seed and straw yield data. The seeds were cleaned and sun-dried to a moisture content of 12%. The straw was also sun-dried properly. Finally, seed and straw yields $plot^{-1}$ were determined and converted to kg ha^{-1}.

1.4.6.7. Recording of data

Emergence of plants were counted from starting to a constant number of plants m^{-2} area of each plot. Experimental data were determined from 15 days of growth duration and continued until harvest. Dry weights of plant were collected by harvesting respective numbers of plants at different specific dates from the inner rows leaving border rows and harvest area for seed. The following data were recorded during the experimentation.

A. Crop growth characters

i. Plant height (at 30, 60, 90 DAS, and harvest)
ii. Branch $plant^{-1}$ (at 30, 60, 90 DAS and harvest)
iii. Nodule count $Plant^{-1}$ (at 50, 60, 70 and 80 DAS)
iv. Above ground dry weight $plant^{-1}$ (at 30, 60, and 90 DAS)

B. Yield and other crop characters

v. Pods plant^{-1} (no.)

vi. Thousand seed weight (g)

vii. Seed yield (kg ha^{-1})

viii. Stover yield (kg ha^{-1})

ix. Biological yield (kg ha^{-1})

x. Harvest index (%)

1.5. Detailed procedures for recording data

A brief outline of the data recording procedure followed during the study given below:

1.5.1. Crop growth characters

1.5.1.1. Plant height

The height of 10 randomly selected plants from each plot for every treatment of all three replication was taken care of at harvest and after 30, 60, 90 and days of sowing of the seeds of BARI Mosur-6. Plant height was measured from the above-ground portion of the plants.

1.5.1.2. Branch plant^{-1}

The branches plant^{-1} were counted carefully from 10 randomly selected plants from each plot for every treatment of all three replications when it became 30, 60, and 90 days after sowing and at harvest.

1.5.1.3. Nodule count plant^{-1}

The nodule plant^{-1} were counted carefully from 10 randomly selected plant from each plot for every treatment of all three replications when it became 50, 60, 70, and 80 days after sowing. Then it was averaged.

1.5.1.4. Above ground dry weight of plant (kg ha^{-1})

10 randomly selected plants from each plot were harvested after 30, 60, and 90 days of sowing. Then the plants were dried properly, and their weight was taken to make them average for each treatment.

1.5.2. Yield and other crop characters

1.5.2.1. Pods plant^{-1}

The pods of five preselected plants were collected from each plot at the time of harvest, counted total number, and then averaged to get pod plant^{-1}.

1.5.2.2. Thousand seed weight (g)

A thousand seeds from each plot were collected, and the digital electric balance in g took their weight.

1.5.2.3. Seed yield (kg ha^{-1})

Seeds of 1 m^2 area in each plot were weighed and then converted into kg ha^{-1}. The seed weight was taken at 12% moisture content of the seeds.

1.5.2.4. Stover yield (kg ha^{-1})

Stover of a central 1 m^2 area in each plot was sun-dried and weighed. Then the weight was converted to kg ha^{-1}.

1.5.2.5. Biological yield (kg ha^{-1})

The biological yield was calculated by adding the seed yield and stover yield.

Biological yield = seed yield + Stover yield.

1.5.2.6. Harvest index

The Harvest index denoted the ratio of economic yield (seed yield) to biological yield and was calculated with the following formula.

$$\text{Harvest index (\%)} = \frac{Seed\ \ yield}{Biological\ \ yield} \times 100$$

1.6. Statistical analysis of data

The data obtained for different parameters will be statistically analyzed following the computer-based software Statistix V.10 and two-way analysis of variance (ANOVA). Fisher’s least significant difference (LSD) test at the 5% level of significance was applied. Correlation analysis was done considering a 5% level of significance.

CHAPTER IV
RESULTS AND DISCUSSION

This study aimed to determine the effect of synthetic biofertilizer, farm-yard manure, and vermicompost on the course of events and the growth and yield of lentil during the *rabi* season. The data on growth characteristics, yield characteristics, and yield influenced by treatment variables were recorded. The findings, along with potential interpretations, were presented under the following headings:

1.1. Plant height (cm)

Different managements significantly influenced plant height at different days after sowing (DAS) (Figure 2). Plant height increased with increasing the age of the plant up to 90 days after sowing. At 30, 60, and 90 DAS the highest plant height (11.03, 19.85, and 39.70 cm, respectively) was found from T_6, and the lowest (8.73, 1572, and 31.3 cm, respectively) was found from T_0. Variations in plant height due to different combinations and doses of fertilizers were also reported by Ceritoğlu and Erman (2019) and Singh *et al.* (2016). This result also agreed with Datta *et. al.* (2013) who observed that the plant height of lentils increased significantly with farm-yard manure.

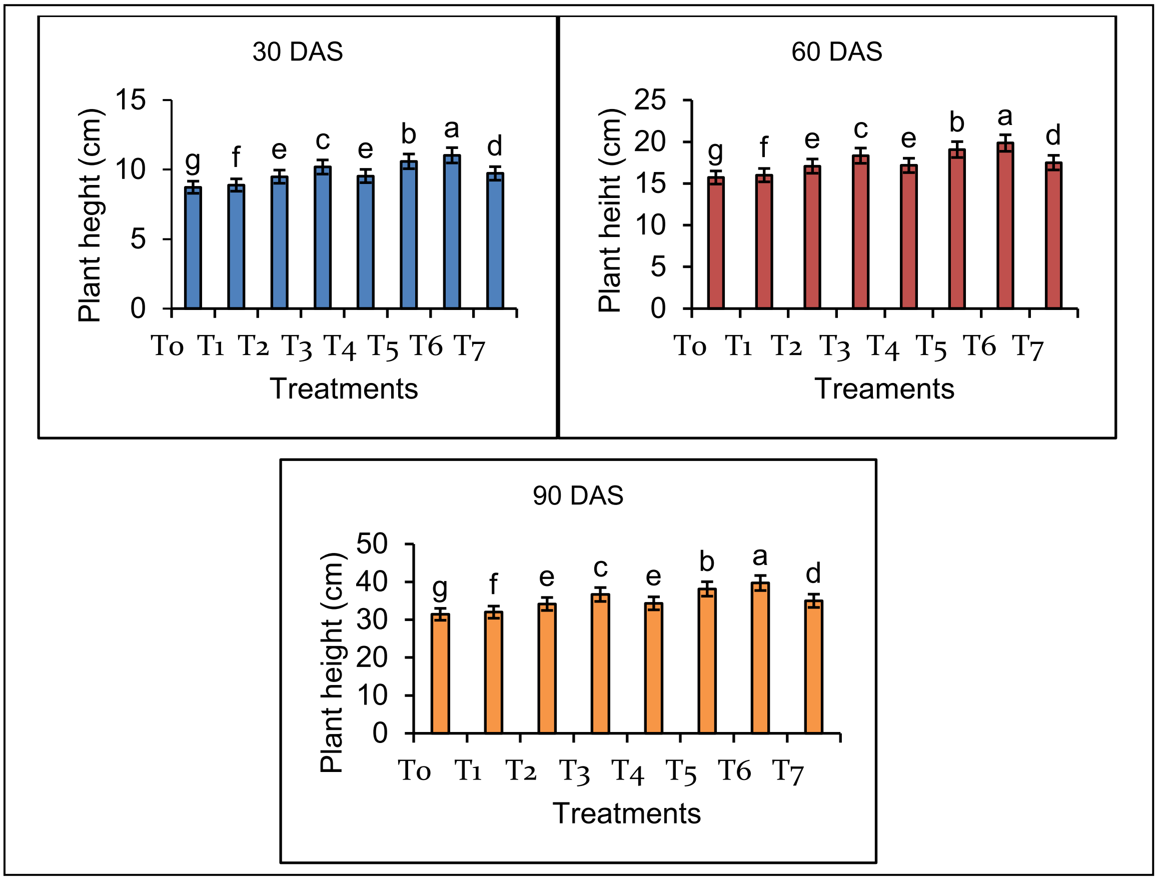
Plant height is an important parameter that reflects the overall growth and development of plants. The seed inoculation with *Rhizobium* (T_1) aimed to enhance plant growth through the introduction of beneficial bacteria. *Rhizobium* is known for its symbiotic association with legumes, promoting nitrogen fixation, which can contribute to improved plant growth and height (Singh *et al.*, 2016). The inclusion of *Azospirillum* , PSB, and KMB in T_2 further aimed to enhance nutrient availability, particularly phosphate, which is essential for plant growth (Datta *et al.*, 2013).

The recommended dose of fertilizer (T_3) was expected to provide adequate nutrients for optimal plant growth. Previous studies have shown that the application of recommended doses of fertilizer can significantly influence plant height (Ceritoğlu and Erman 2019). The incorporation of organic amendments, such as vermicompost (T_5) and farm-yard manure (T_6), aimed to improve soil fertility and nutrient availability. These organic amendments have been reported to enhance plant growth and height by providing additional nutrients and improving soil structure (Ceritoğlu and Erman 2019).

The treatment T_7 (seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + vermicompost + farm-yard manure) combined multiple beneficial factors, including rhizobial inoculation, nutrient availability from organic amendments, and improved soil microbial activity. Previous research has demonstrated that combined treatments can have synergistic effects on plant growth and height (Kumar and Chaudhary 2018).

The influence of different doses of fertilizer management at different DAS was also considered in this study. It is well-known that plants have varying nutrient requirements at different growth stages. By adjusting the fertilizer management timing and dosage, it is possible to optimize nutrient uptake and promote plant growth. Previous studies have reported that timing and dosage of fertilizer management an significantly affect plant height in lentil (Ceritoğlu and Erman 2019).

In conclusion, the results of this study suggest that the different treatments, including seed inoculation with beneficial bacteria, recommended doses of fertilizer, and the incorporation of organic amendments, have the potential to influence the plant height of lentil. Further analysis, including statistical comparisons and examination of growth trends at different DAS intervals, will provide a more comprehensive understanding of the specific effects of each treatment on plant height. These findings can contribute to the development of tailored fertilization strategies to promote optimal plant growth and height in lentil cultivation.



Here, (LSD $_{0.05}$ = 0.06, 0.11 and 0.22 at 30, 60, and 90 DAS respectively) T_0 = Control, T_1 = Seed inoculation with Rhizobium, T_2 = Seed inoculation with Azospirillum + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with Rhizobium + Azospirillum + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with Rhizobium + Azospirillum + PSB + KMB + Vermicompost + FYM

Figure 1. Plant height of lentil as influenced by different fertilizer management at different days after sowing (DAS)

1.2.Branches Plant^{-1}

Different types of biofertilizer management with the combination of organic manures and fertilizer management s significantly affect the branch production of lentils (Table 3). At 30, 60, and 90 days after sowing, the highest number of branches (3.10, 7.75, and 9.30, respectively) was found from T_{6}, and the lowest number of branches (1.00, 2.50, and 3.00) was found from T_0. Zeidan (2007) reported that branching is a genetic character but is also influenced by environmental factors. Choudhary *et al.* (2011) also confirmed that the numbers of branch production vary due to different types of fertilizer applications with the combination of organic manures and fertilizer applications. These results agreed with those of Jamil *et al.* (2008) and Barua *et al.* (2011) who observed that the number of branches palnt^{-1} of lentil increased significantly.

Table 2. Effect of different fertilizer management on branches plant^{-1} on different days after sowing (DAS)

Treatment	Branch plant^{-1} on different days after sowing (DAS)		
	30	**60**	**90**
T_0	1.00 e	2.50 e	3.00 e
T_1	1.70 d	4.25 d	5.10 d
T_2	1.90 cd	4.75 cd	5.70 cd
T_3	2.03 b-d	5.08 b-d	6.10 b-d
T_4	2.00 b-d	5.00 b-d	6.00 b-d
T_5	2.33 b	5.83 b	7.00 b
T_6	3.10 a	7.75 a	9.30 a
T_7	2.10 bc	5.25 bc	6.30 bc
LSD $_{(0.05)}$	0.158	0.39	0.47
CV (%)	0.338	0.85	1.015

In a column means having a similar letter (s) are statistically similar, and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability. Here, T_0 = Control, T_1 = Seed inoculation with *Rhizobium* , T_2 = Seed inoculation with *Azospirillum* + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

Based on the findings of this study, it can be concluded that treatment T_6, which involved the application of a recommended dose of fertilizer (RDF) combined with farm-yard manure (FYM), exhibited the most favorable impact on the branch plant^{-1} of lentil. The incorporation of FYM as an organic amendment has been reported to enhance soil fertility, improve nutrient availability, and promote beneficial microbial activity, leading to improved plant growth and architecture (Choudhary *et al.*, 2011). The synergistic effects of RDF and FYM in T_6 likely contributed to the observed positive outcomes, resulting in enhanced branch development and overall plant architecture. These findings align with previous studies highlighting the beneficial role of organic amendments in promoting branching and maximizing yield potential in lentil crops (Barua *et al.*, 2011).

The significant improvement in branch plant^{-1} observed in T_6 can have implications for the overall productivity and quality of lentil crops. A well-branched plant architecture allows for increased flowering and pod formation, ultimately leading to higher yield potential. Furthermore, a robust branching pattern ensures better light interception, nutrient distribution, and efficient resource utilization, which are critical factors influencing the overall performance of lentil plants. The positive impact of T_6 on branch plant^{-1} highlights the importance of incorporating organic amendments, such as FYM, alongside recommended doses of fertilizer to optimize lentil production.

While T_6 emerged as the most effective treatment in terms of branch plant^{-1}, further investigations are warranted to comprehensively evaluate other growth parameters, such as yield, biomass accumulation, and nutrient uptake. Additionally, assessing the long-term effects of T_6 on soil health and sustainability aspects would provide valuable insights into the practical applicability of this treatment in lentil cultivation systems.

In conclusion, based on the results obtained in this study, treatment T_6, involving the application of RDF along with FYM, demonstrated superior performance in terms of branch plant^{-1} in lentil. These findings underline the potential benefits of incorporating organic amendments into fertilization practices to improve plant architecture and maximize yield potential.

1.3. Nodule production

Different types of fertilizer applications with the combination of organic manures and fertilizer applications significantly affect nodule production of lentils at 50, 60, 70, and 80 days after sowing (DAS) (Table 4). Nodule number increased with age, reaching a peak at around 70 DAS and thereafter declined irrespective of different treatment applications. AT 50, 60, 70, and 80 days after sowing (DAS) the highest number of the nodule (18.73, 24.34, 36.53, and, 27.39, respectively) was found from T_6 (RDF + FYM). The lowest number of nodules (14.10, 18.33, 27.49, and 20.62) was found from T_0 (Control). These results conform with Datta *et al.* (2013), who reported that nodule production varied due to different doses of fertilizer application. These results agreed with those of Singh *et. al.* (2016) who observed that the number of nodules palnt^{-1} of lentil increased significantly up to different doses of fertilizers ha^{-1} with different combinations of organic manure application. The observed variations in nodule production per plant among the treatments can be attributed to several factors (Jarrell and Beverly 1981). Biofertilizers containing *Rhizobium* bacteria establish a symbiotic relationship with lentil plants, promoting nodulation and nitrogen fixation. Farm-yard manure and vermicompost contribute to soil fertility, nutrient availability, and microbial activity, creating an environment conducive to nodule development (Kumar *et al.,* 2022b) The combined application of RDF and FYM appeared to optimize the growth and performance of lentil plants, leading to enhanced nodule production per plant (Pandit and Mookherjee 2018). The study highlights the positive influence of biofertilizer, farm-yard manure, and vermicompost on nodule production per plant, as well as the growth and yield of lentil crops. The combined application of a recommended dose of fertilizer and farm-yard manure emerged as the most effective treatment for promoting nodulation and overall plant performance (Muindi *et al.*, 2020). These findings emphasize the significance of incorporating organic amendments in lentil farming systems to enhance nutrient availability, soil health, and sustainable agricultural practices.

Table 3. Effect of different fertilizer management on nodule number plant^{-1} on different days after sowing (DAS)

Treatment	Number of nodules plant^{-1} at different days after sowing (DAS)			
	50	**60**	**70**	**80**
T_0	14.10 f	18.33 f	27.49 f	20.62 f
T_1	14.90 e	19.37 e	29.06 e	21.79 e
T_2	15.50 d	20.15 d	30.23 d	22.67 d
T_3	16.80 c	21.84 c	32.76 c	24.57 c
T_4	15.70 d	20.41 d	30.62 d	22.96 d
T_5	17.77 b	23.09 b	34.65 b	25.98 b
T_6	18.73 a	24.35 a	36.53 a	27.39 a
T_7	15.77 d	20.49 d	30.75 d	23.06 d
LSD $_{(0.05)}$	0.21	0.28	0.41	0.31
CV (%)	0.46	0.59	0.41	0.67

In a column means having a similar letter (s) are statistically similar, and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability. Here, T_0 = Control, T_1 = Seed inoculation with *Rhizobium* , T_2 = Seed inoculation with *Azospirillum* + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

1.4. Dry weight plant^{-1}

The effect of different fertilizer managements had a significant effect on total dry weight plant^{-1} on different days after sowing (Table 5). At 30 days after sowing, the highest amount of dry weight (1.46 g) was found from T_6 (RDF + FYM), and the lowest (0.89 g) amount was found from T_0 (Control). At 60 after sowing, the highest amount of dry weight (10.19 g) was found from T_6 (RDF + FYM), and the lowest (6.29 g) amount was found from T_0 (Control). At 90 days after sowing, the highest (18.34 g) amount of dry weight was found from T_6 (RDF + FYM), and the lowest (11.33 g) accordingly amount was found from T_0 (Control). Variation of plant dry matter due to different doses of fertilizers was also reported by Datta *et al.* (2013) and Farghali and Hossain (1995) in lentil. These results agreed with those of Ceritoğlu and Erman (2019) and Kumar and Chandra (2008), who observed that the number of dry weights palnt^{-1} of lentil increased significantly up to different doses of fertilizers ha^{-1} with different combinations of organic manure application. The results indicate that the application of biofertilizer, FYM, and vermicompost positively influenced dry weight per plant in lentil. However, variations in the effectiveness of the treatments are observed. The treatment combining recommended dose of fertilizer (RDF) with FYM exhibited the highest dry weight per plant, suggesting a synergistic effect between inorganic and organic nutrient sources. Other treatments also showed improvements in plant height, shoot biomass, nodulation, and dry weight compared to the control group, but to a lesser extent. The observed variations in dry weight per plant among the treatments can be attributed to several factors. Biofertilizers containing *Rhizobium* bacteria establish a beneficial symbiotic relationship, promoting nodulation and nitrogen fixation, which contributes to increased plant biomass (Pierre *et al.,* 2014). Farm-yard manure and vermicompost enhance soil fertility, nutrient availability, and microbial activity, creating a favorable environment for plant growth and dry weight accumulation. The combined application of RDF and FYM appears to optimize the growth and performance of lentil plants, resulting in increased dry weight per plant (Singh *et al.,* 2010). The comparative study highlights the positive influence of biofertilizer, farm-yard manure, and vermicompost on dry weight per plant, as well as the growth, yield, and nodulation of lentil crops. The combined application of recommended doses of fertilizer and farm-yard manure emerges as the most effective treatment for promoting plant biomass and dry weight accumulation (Kumar *et al.*, 2022a). These findings emphasize the importance of incorporating organic amendments in lentil farming systems to enhance nutrient availability, soil health, and sustainable agricultural practices.

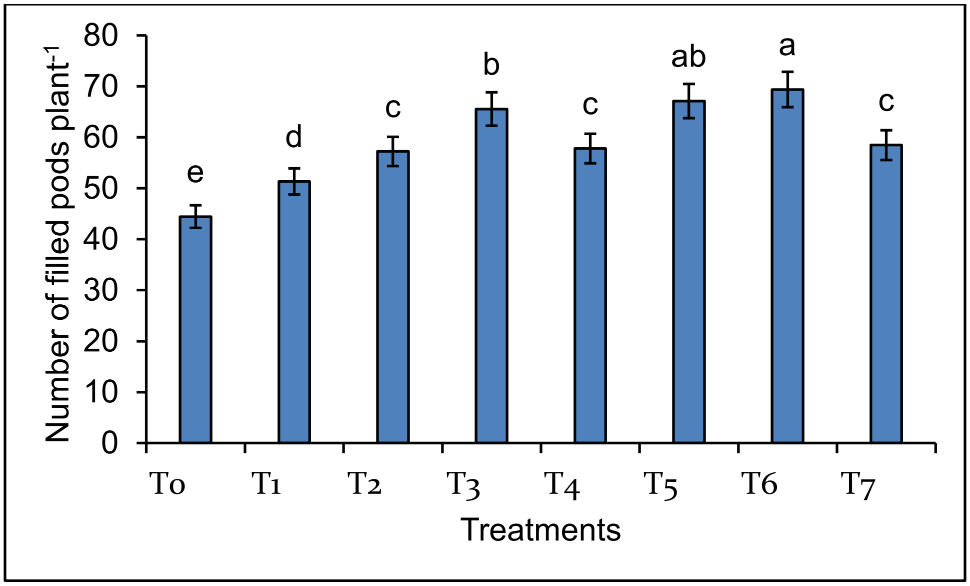
Table 4. Effect of different fertilizer management on above ground dry-weight plant^{-1} (g) on different days after sowing (DAS)

Treatment	Dry weight plant^{-1} (g) on different days after sowing (DAS)		
	30	**60**	**90**
T_0	0.89 f	6.29 f	11.33 f
T_1	1.04 e	7.24 e	13.04 e
T_2	1.05 e	7.32 e	13.18 e
T_3	1.22 c	8.57 c	15.42 c
T_4	1.06 e	7.41 e	13.33 e
T_5	1.36 b	9.54 b	17.18 b
T_6	1.46 a	10.19 a	18.34 a
T_7	1.14 d	7.95 d	14.31 d
LSD $_{(0.05)}$	0.026	0.18	0.32
CV (%)	0.06	0.39	0.69

In a column means having a similar letter (s) are statistically similar, and those having dissimilar letter (s) differ significantly by LSD at 0.05 level of probability. Here, T_0 = Control, T_1 = Seed inoculation with *Rhizobium* , T_2 = Seed inoculation with *Azospirillum* + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

1.5. Filled pods plant^{-1}

Different fertilizer applications' effects were significant, and some treatments had a non-significant effect on total filled pod plant^{-1} on different days after sowing (Figure 3). The highest amount of filled pod plant^{-1} (69.39 and 67.13) was found from T_6 (RDF + FYM), and T_5 (RDF + Vermicompost), respectively, and the lowest (44.45) amount of filled pod plant^{-1} was found from T_0 (Control). The effect of different fertilizer managements had non-significant found from T_2 (Seed inoculation with *Azospirillum* + PSB + KMB), T_4 (Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB), and T_7 (Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM), respectively. Variation in filled pod plant^{-1} in different fertilizer managements was also reported by Saket *et al.* (2014) in lentil. These results agreed with those of Singh *et al.* (2002), who observed that the filled pod plant^{-1} of lentil increased significantly up to different doses of fertilizers ha^{-1} with different combinations of organic manure application. Biofertilizers consist of beneficial microorganisms, such as nitrogen-fixing bacteria, that promote plant growth and enhance nutrient availability. The application of biofertilizer has been reported to positively influence the filled pod per plant parameter in lentil crops. The presence of nitrogen-fixing bacteria in biofertilizers enhances nitrogen fixation, which leads to improved plant growth, increased flowering, and ultimately, more filled pods per plant. FYM is a traditional organic fertilizer that provides a rich source of organic matter, nutrients, and beneficial microorganisms to the soil. Its application can significantly impact the filled pod per plant parameter in lentil cultivation. FYM improves soil structure, nutrient retention, and water-holding capacity, which in turn promotes root development, flowering, and pod formation. The increased availability of nutrients and favorable soil conditions contribute to a higher number of filled pods per plant. Vermicompost is a nutrient-rich organic fertilizer produced through the decomposition of organic waste by earthworms. It enhances soil fertility, improves nutrient availability, and enhances microbial activity. Studies have shown that the application of vermicompost positively influences the filled pod per plant parameter in lentil crops. The improved soil fertility and nutrient supply from vermicompost result in better vegetative growth, increased flowering, and ultimately more filled pods per plant.



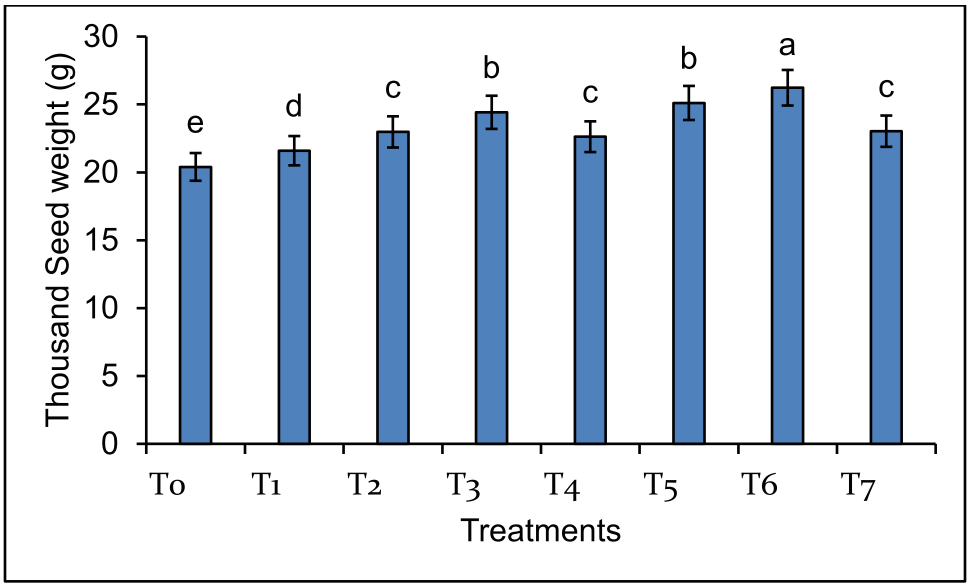
Here, (LSD $_{0.05}$ = 1.15) T_0 = Control, T_1 = Seed inoculation with *Rhizobium* , T_2 = Seed inoculation with *Azospirillum* + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

Figure 2. Filled pods plant^{-1} of lentil as influenced by different fertilizer management

The results indicate that the application of biofertilizer, FYM, and vermicompost positively influenced the number of filled pods per plant in lentil. However, variations in the effectiveness of the treatments are observed. The treatment combining a recommended dose of fertilizer (RDF) with FYM exhibited the highest number of filled pods per plant, suggesting a synergistic effect between inorganic and organic nutrient sources. Other treatments also showed improvements in plant height, shoot biomass, nodulation, and filled pod number compared to the control group, but to a lesser extent (Singh *et al.*, 2002). The observed variations in the number of filled pods per plant among the treatments can be attributed to several factors. Biofertilizers containing *Rhizobium* bacteria establish a beneficial symbiotic relationship, promoting nodulation and nitrogen fixation, which contributes to increased pod development and filled pod number. Farm-yard manure and vermicompost enhance soil fertility, nutrient availability, and microbial activity, creating a favorable environment for plant growth and filled pod formation. The combined application of RDF and FYM appears to optimize the growth and performance of lentil plants, resulting in an increased number of filled pods per plant (Saket *et al.*, 2014). The comparative study highlights the positive influence of biofertilizer, farm-yard manure, and vermicompost on the number of filled pods per plant, as well as the growth, yield, and nodulation of lentil crops. The combined application of recommended dose of fertilizer and farm-yard manure emerges as the most effective treatment for promoting filled pod development and maximizing lentil yield (Kumar *et al.*, 2022b). These findings underscore the importance of incorporating organic amendments in lentil farming systems to enhance pod formation, yield potential, and sustainable agricultural practices. The utilization of biofertilizer, farm-yard manure (FYM), and vermicompost in lentil cultivation has demonstrated positive effects on the filled pod per plant parameter. These organic fertilizers enhance soil fertility, nutrient availability, and microbial activity, leading to improved plant growth and increased pod formation. Incorporating these organic inputs into lentil production practices can be beneficial for optimizing yield and overall crop performance. However, further research and field trials are needed to determine the optimal application rates and combinations of these organic fertilizers for different lentil varieties and agroecological conditions.

1.6. Thousand-seed weight

The effect of different fertilizer managements had significant effects on 1000-seed weight (Figure 4). However, numerically the highest amount of 1000 seed weight (26.23 g) was found from T_6 (RDF + FYM), and the lowest (20.40 g) was found from T_0 (Control). Variation in 1000-seed weight in different fertilizer managements was also reported by Saket *et al.* (2014) in lentil. These results agreed with those of Singh *et al.* (2002), who observed that the thousand seed weights of lentil increased significantly up to different doses of fertilizers ha^{-1} with different combinations of organic manure application.



Here, (LSD $_{0.05}$ = 0.35) T_0 = Control, T_1 = Seed inoculation with *Rhizobium* , T_2 = Seed inoculation with *Azospirillum* + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

Figure 3. Thousand seed weight of lentil as influenced by different fertilizer management

The treatments mentioned above encompass a range of approaches to improve lentil seed size and quality, as represented by the Thousand-seed weight parameter. The control group (T_0) provides a baseline for comparison, allowing for an assessment of the relative effectiveness of the treatments (Chapagain and Riseman 2012).

Seed inoculation with *Rhizobium* (T_1) is expected to enhance nitrogen fixation, leading to improved plant vigour and ultimately contributing to increased seed size and Thousand-seed weight (Ugile *et al.*, 2020). Similarly, the inclusion of *Azospirillum*, PSB, and KMB in T_2 can promote nutrient availability, particularly phosphorus and potassium, which are essential for plant growth and development. This treatment may result in larger seeds compared to the control group (Prasad 2022).

The recommended dose of fertilizer (RDF) (T_3) provides a balanced nutrient supply to the lentil plants. Adequate nutrition supports healthy plant growth, potentially leading to larger seeds and increased thousand-seed weight. Combining the benefits of *Rhizobium*, *Azospirillum* , PSB, and KMB in T_4 can further enhance nutrient uptake and plant growth, potentially resulting in improved seed quality (Modi and Jha 2022).

The incorporation of organic fertilizers, such as vermicompost (T_5) and farm-yard manure (FYM) (T_6), alongside the recommended dose of fertilizer (RDF), enrich the soil with organic matter and nutrients. These organic inputs improve soil fertility, nutrient availability, and microbial activity, which can positively influence lentil growth and seed development. Consequently, lentils treated with T_5 and T_6 may exhibit larger seeds and higher thousand-seed weight.

The comprehensive approach in T_7, combining seed inoculation with beneficial bacteria (*Rhizobium*, *Azospirillum* , PSB, KMB) and the addition of vermicompost and FYM, offers the potential for synergistic effects. This treatment leverages multiple mechanisms, including nitrogen fixation, nutrient availability, and improved soil fertility, resulting in enhanced lentil growth and seed quality. As a result, T_7 has the potential to yield lentils with a higher Thousand-seed weight compared to the other treatments. The treatments examined in this discussion offer various strategies to improve the Thousand-seed weight of lentils. Seed inoculation with beneficial bacteria, such as *Rhizobium* and *Azospirillum* , combined with the addition of organic fertilizers like vermicompost and farm-yard manure, as well as the application of the recommended dose of fertilizer, can positively influence lentil seed size and quality. By implementing these interventions, lentil growers have the potential to optimize thousand-seed weight, leading to improved crop productivity and quality. However, further field trials and research are necessary to evaluate the efficacy of these treatments under different agroecological conditions and cultivars.

1.7. Seed yield

Different fertilizer managements in different methods and amounts exerted a significant effect on the seed yield of lentil (Figure 5). The highest amount of seed yield (1.95 t ha^{-1}) was found from T_6, which was statistically similar to T_5 (1.91 t ha^{-1}). The lowest seed yield (1.11 t ha^{-1}) was found from T_0. Sahu *et al.* (2017) and Sonet *et al.* (2020) reported that seed yield varies with different methods and doses of fertilizer applications in the case of lentil. The treatments discussed above encompass various strategies to enhance seed yield in lentil cultivation. By comparing the outcomes with the control group (T_0), the relative effectiveness of each treatment can be evaluated.

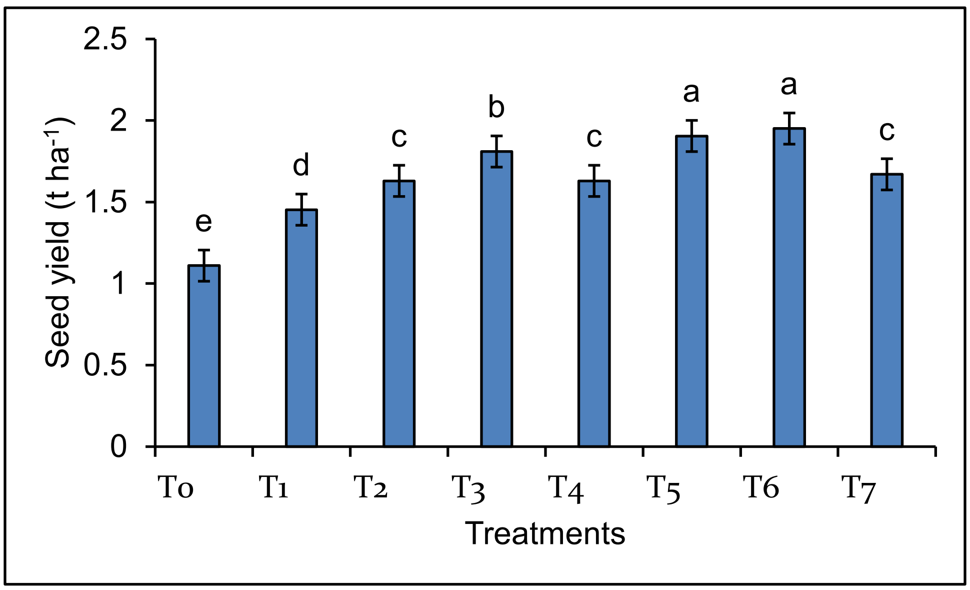
Seed inoculation with *Rhizobium* (T_1) promotes nitrogen fixation, which enhances plant growth and can result in increased seed yield. The presence of *Azospirillum*, PSB, and KMB in T_2 further supports nutrient availability, particularly phosphorus and potassium, contributing to improved plant growth and potentially higher seed yield.

The recommended dose of fertilizer (RDF) (T_3) provides balanced nutrition to the plants, ensuring optimal growth and development. This treatment serves as a standard for evaluating the efficacy of other interventions. Combining *Rhizobium, Azospirillum* , PSB, and KMB in T_4 can potentially enhance nutrient uptake, nitrogen fixation, and overall plant vigor, leading to increased seed yield compared to individual treatments.

The incorporation of vermicompost with RDF (T_5) enriches the soil with organic matter and nutrients, improving nutrient availability and soil fertility. This combination can stimulate plant growth and contribute to a higher seed yield. Similarly, the addition of farm-yard manure with RDF (T_6) enhances soil fertility, nutrient availability, and microbial activity, thereby supporting plant growth and potentially increasing seed yield (Sahu *et al.*, 2017).

The comprehensive approach in T_7, combining seed inoculation with beneficial bacteria (*Rhizobium*, *Azospirillum* , PSB, KMB), vermicompost, and farm-yard manure, offers multiple mechanisms to improve seed yield. The combined effects of increased nutrient availability, nitrogen fixation, and enhanced soil fertility provide a favorable environment for lentil growth, leading to higher seed yield compared to other treatments.

The treatments discussed in this study provide various strategies to enhance seed yield in lentil cultivation. Seed inoculation with beneficial bacteria, such as *Rhizobium* and *Azospirillum* , along with the incorporation of organic fertilizers like vermicompost and farm-yard manure, combined with the recommended dose of fertilizer, can positively influence lentil productivity. By implementing these interventions, farmers have the potential to optimize seed yield and improve overall crop productivity. However, it is important to consider the specific agroecological conditions and cultivars when implementing these treatments. Further research and field trials are warranted to assess the long-term effectiveness and sustainability of these interventions in lentil production systems (Sonet *et al.*, 2020).

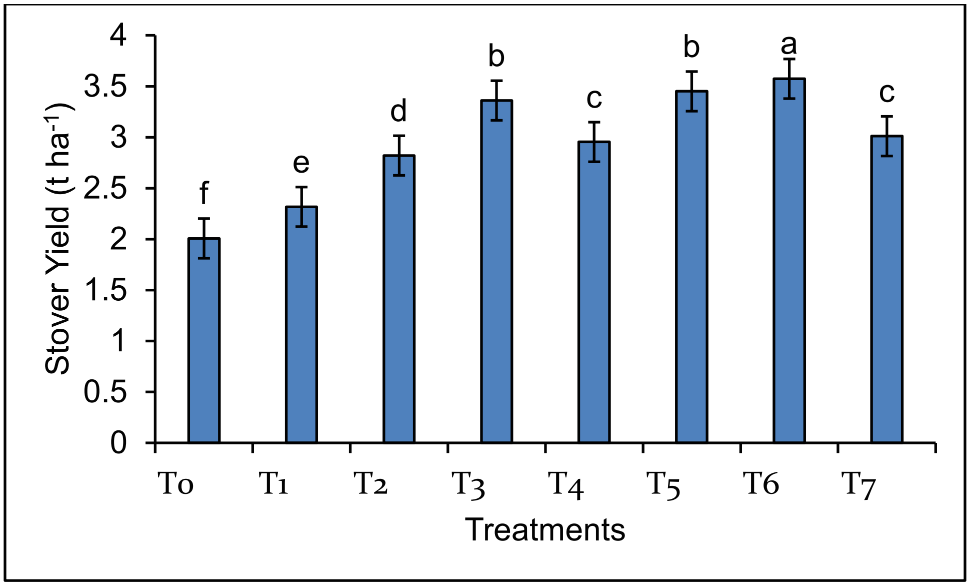


Here, (LSD $_{0.05}$ = 0.03) T_0 = Control, T_1 = Seed inoculation with Rhizobium, T_2 = Seed inoculation with Azospirillum + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with Rhizobium + Azospirillum + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with Rhizobium + Azospirillum + PSB + KMB + Vermicompost + FYM

Figure 4. Seed yield of lentil as influenced by different fertilizer management

1.8. Stover yield

The combination of fertilizer management had a significant effect on the stover yield of lentil (Figure 6). The highest amount of stover yield (3.57 t ha^{-1}) was found from T_6 (RDF + FYM). The lowest amount of stover yield (2.01 t ha^{-1}) was found from T_0. This result is in conformity with Kumar *et al.* (2022a) who reported that straw yield also varied significantly among the different combinations of organic, inorganic, and bio-fertilizer management.



Here, (LSD $_{0.05}$ = 0.04) T_0 = Control, T_1 = Seed inoculation with *Rhizobium* , T_2 = Seed inoculation with *Azospirillum* + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

Figure 5. Stover yield of lentil as influenced by different fertilizer management

Control (T_0): The control group represents the standard practice without any additional treatments. Comparing the stover yield of lentils in this group to those in the other treatments provides a baseline for assessing the relative effectiveness of the interventions. Seed Inoculation with *Rhizobium* (T_1): *Rhizobium* inoculation establishes a symbiotic relationship with lentil plants, facilitating nitrogen fixation. This process enhances plant growth and biomass accumulation, leading to increased stover yield compared to the control group.

Seed Inoculation with *Azospirillum* + PSB + KMB (T_2): The presence of *Azospirillum*, phosphate solubilizing bacteria (PSB), and potassium mobilizing bacteria (KMB) promotes nutrient availability, particularly phosphorus and potassium. These nutrients play a vital role in plant growth and development, contributing to increased stover yield through improved nutrient uptake and utilization.

Recommended Dose of Fertilizer (RDF) (T_3): The application of the recommended dose of fertilizer ensures adequate nutrient supply for optimal plant growth. This treatment supports robust vegetative growth and biomass production, potentially resulting in higher stover yield compared to the control group.

Seed Inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (T_4): Combining *Rhizobium* inoculation with *Azospirillum*, PSB, and KMB can synergistically enhance nutrient availability, nitrogen fixation, and overall plant vigor. This combined effect may contribute to increased stover yield compared to individual treatments.

RDF + Vermicompost (T_5): Vermicompost, as an organic amendment, enriches the soil with nutrients and enhances microbial activity. Combining vermicompost with the recommended dose of fertilizer can improve soil fertility and nutrient availability, promoting vigorous plant growth and potentially increasing stover yield.

RDF + Farm-Yard Manure (FYM) (T_6): Farm-yard manure (FYM) provides organic matter and nutrients to the soil, improving soil fertility and enhancing nutrient availability for plants. Combining FYM with the recommended dose of fertilizer supports optimal nutrient supply, which can result in increased stover yield.

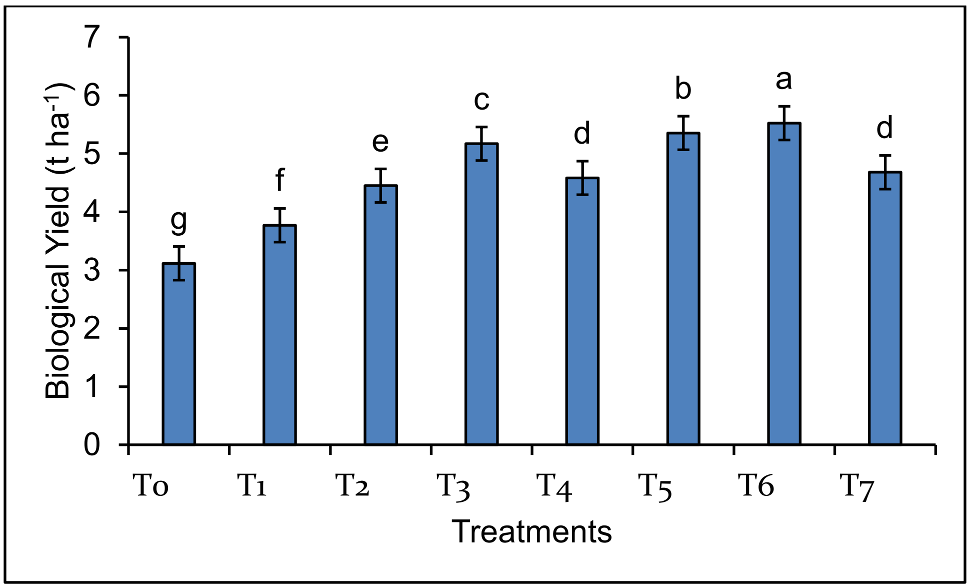
Seed Inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM (T_7): This treatment integrates all the interventions mentioned above, including seed inoculation with beneficial bacteria (*Rhizobium, Azospirillum*, PSB, KMB), vermicompost, and FYM. The combined effects of improved nutrient availability, nitrogen fixation, and enhanced soil fertility provide a comprehensive approach to promote lentil growth and maximize stover yield.

It is important to consider specific agroecological conditions and cultivars when implementing these treatments. Further research and field trials are necessary to assess the long-term effectiveness, economic viability, and sustainability of these interventions in lentil production systems.

By implementing these strategies, farmers have the potential to optimize stover yield in lentil cultivation, which can contribute to increased biomass availability for various purposes, such as animal feed, organic matter for soil health, and renewable energy production.

1.9. Biological Yield

The combination of fertilizer application had a significant effect on the biological yield of lentil (Figure. 7). The highest amount of biological yield (5.52 t ha^{-1}) was found from T_6 (RDF + FYM). The lowest amount of biological yield (3.12 t ha^{-1}) was found from T_0. This result is in conformity with Singh *et al.* (2010) who reported that straw yield also varied significantly among the different combinations of organic, inorganic, and bio-fertilizer applications.



Here, (LSD $_{0.05}$ = 0.04) T_0 = Control, T_1 = Seed inoculation with *Rhizobium* , T_2 = Seed inoculation with *Azospirillum* + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

Figure 6. Biological yield of lentil as influenced by different fertilizer management

Bacteria like *Rhizobium*, *Azospirillum*, PSB, and KMB enhance nutrient availability, nitrogen fixation, and overall plant vigour, contributing to increased biological yield. Additionally, incorporating organic amendments such as vermicompost and farm-yard manure further improves soil fertility, nutrient cycling, and microbial activity, resulting in higher crop productivity (Singh *et al.*, 2010).

The recommended dose of fertilizer (RDF) serves as a benchmark for nutrient management, ensuring adequate nutrient supply for optimal crop growth. However, the integration of seed inoculation with beneficial bacteria and organic amendments (T_7) shows a holistic approach that combines multiple mechanisms to maximize biological yield.

It is important to consider specific crop requirements, soil conditions, and local agroecological factors when implementing these treatments. Crop cultivars may also respond differently to various interventions, highlighting the need for further research and field trials to optimize the application rates and timing of these treatments.

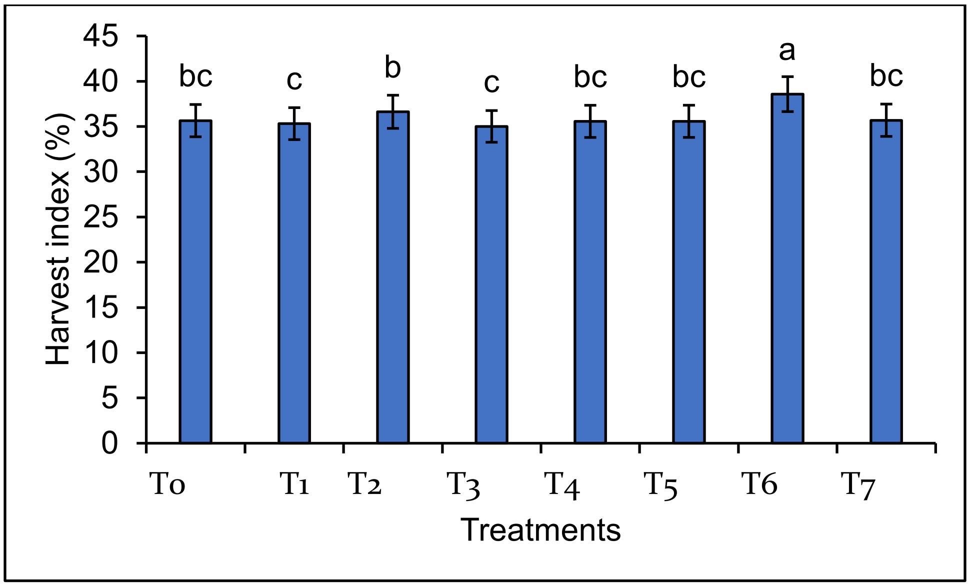
By implementing these strategies, farmers can improve the biological yield of their crops, leading to increased biomass production, food security, and economic benefits. Furthermore, the enhanced nutrient availability, soil fertility, and microbial activity resulting from these treatments contribute to sustainable agriculture practices and the long-term health of agricultural ecosystems.

Further research should focus on evaluating the economic feasibility, environmental impact, and scalability of these interventions in different cropping systems. Additionally, studying the long-term effects on soil health, nutrient cycling, and the ecological balance of microbial communities will provide valuable insights for sustainable agriculture.

In conclusion, the treatments involving seed inoculation with beneficial bacteria, organic amendments, and the recommended dose of fertilizer offer promising strategies to enhance biological yield. These interventions provide a comprehensive approach to optimize nutrient availability, promote nitrogen fixation, improve soil fertility, and support vigorous crop growth, ultimately leading to increased biomass production and crop productivity (Lamlom *et al.*, 2023).

1.10. Harvest Index

The combination of fertilizer management had a significant effect on the harvest index of lentil (Figure 8). The highest harvest index (38.57) was found from T_6 (RDF + FYM). The lowest harvest index (35.01 and 35.31) was found in T_3 and T_0. This result is in conformity with Singh *et al.* (2010), who reported that straw yield also varied significantly among the different combinations of organic, inorganic, and bio-fertilizer applications.



Here, (LSD $_{0.05}$ = 0.59) T_0 = Control, T_1 = Seed inoculation with *Rhizobium* , T_2 = Seed inoculation with *Azospirillum* + PSB + KMB (Phosphate solubilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB (Potassium mobilizing bacteria), T_5 = RDF + Vermicompost, T_6 = RDF + FYM (Farm-yard manure), T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM

Figure 7. Harvest index of lentil as influenced by different fertilizer management

The harvest index is an important parameter that reflects the efficiency of resource allocation and utilization in crop production. It represents the proportion of the total biomass allocated to the harvested portion, such as seeds or fruits. In the case of lentil (*Lens culinaris*), the harvest index is a crucial determinant of overall crop productivity and economic yield (Singh *et al.*, 2010). Biofertilizers, such as *Rhizobium* and *Azospirillum*, play a vital role in enhancing nitrogen fixation and nutrient availability in legume crops like lentil. *Rhizobium* inoculation promotes the formation of nitrogen-fixing nodules on the plant roots, leading to increased nitrogen uptake and utilization. This improved nitrogen availability can result in better partitioning of resources towards seed development and ultimately lead to an increased harvest index in lentil plants (Cocking, 2003).

Farm-yard manure, a traditional organic amendment, is rich in organic matter and essential nutrients. The incorporation of FYM into the soil enhances soil fertility, improves nutrient availability, and promotes microbial activity. The increased nutrient supply, particularly nitrogen and phosphorus, can positively impact lentil crop growth and development, resulting in a higher harvest index. FYM also improves soil structure and water-holding capacity, which further supports lentil productivity and seed formation (Rasool *et al.*, 2008).

Vermicompost, which is produced through the decomposition of organic materials by earthworms, is a nutrient-rich organic amendment. It contains beneficial microorganisms, plant growth-promoting substances, and micronutrients. The application of vermicompost to lentil crops improves soil fertility, nutrient cycling, and overall plant health. The increased availability of essential nutrients and improved soil conditions contribute to better resource utilization and, consequently, a higher harvest index (Mupambwa and Mnkeni 2018).

The combined application of biofertilizer, FYM, and vermicompost can result in synergistic effects on the harvest index of lentil. The biofertilizer provides enhanced nitrogen fixation and nutrient availability, while FYM and vermicompost contribute to improved soil fertility and nutrient cycling. This integrated approach optimizes nutrient uptake, promotes vigorous vegetative growth, and improves reproductive processes, leading to higher seed formation and a greater harvest index.

CHAPTER V
SUMMARY AND CONCLUSION

An experiment was conducted at the Sher-e-Bangla Agricultural University farm, Dhaka-1207, Bangladesh during the period from November 2021 to March 2022 to study the performance of lentil (BARI Masur-6) as affected by different doses of combined fertilizer application. Lentil was used as the test crop for this experiment. The experiment comprised of single factor comprising eight treatments viz. T_0 = Control, T_1 = Seed inoculation with *Rhizobium*, T_2 = Seed inoculation with *Azospirillum* + PSB (Phosphate solubilizing bacteria) + KMB (Potassium mobilizing bacteria), T_3 = RDF (Recommended dose of fertilizer), T_4 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB, T_5 = RDF + Vermicompost, T_6 = RDF + FYM, T_7 = Seed inoculation with *Rhizobium* + *Azospirillum* + PSB + KMB + Vermicompost + FYM. Seeds of “BARI Mosur-6” were used in the experiment. Data were collected on different aspects of growth, yield attributes, yield, and harvest index of Lentil including soil properties and nutrient contents.

The results revealed that treatment T_6 (RDF + FYM) exhibited its superiority compared to other organic and inorganic fertilizer treatments in terms of yield of Lentil. Treatment T_5 yielded like the treatment of $T_{6,}$ and it is the second highest in position in terms of production. Plant height increased with increasing the age of the plant up to 90 days after sowing. At 30, 60, and 90 days after sowing, the highest plant height (39.70 cm) was found from T_6, and the lowest (31.3 cm) was found from T_0. The highest number of branches (9.30) was found from $T_{6,}$ and the lowest number of branches (3.00) was found from T_0. The nodule number increased with age, reaching a peak at around 70 DAS, and thereafter declined irrespective of different treatment applications. The highest number of nodules (27.39) was found from T_6 (RDF + FYM), and the lowest number of nodules (20.62) was found from T_0 (Control). The highest (18.34 g) amount of dry weight was found from T_6 (RDF + FYM), and the lowest (11.33 g) accordingly amount was found from T_0 (Control). The highest amount of filled pod plant^{-1} (69.39 and 67.13) was found from T_6 (RDF + FYM), and T_5 (RDF + Vermicompost), respectively, and the lowest (44.45) amount of filled pod plant^{-1} was found from T_0 (Control). Numerically the highest amount of 1000 seed weight (26.23 g) was found from T_6 (RDF + FYM), and the lowest (20.40 g) was found from T_0 (Control). The highest seed yield (1.95 t ha^{-1}) was found in T_6, which was statistically similar to T_5 (1.91 t ha^{-1}). The lowest seed yield (1.11 t ha^{-1}) was found from T_0. The highest stover yield (3.57 t ha^{-1}) was found from T_6 (RDF + FYM). The lowest amount of stover yield (2.01 t ha^{-1}) was found from T_0. The highest biological yield (5.52 t ha^{-1}) was found from T_6 (RDF + FYM). The lowest amount of biological yield (3.12 t ha^{-1}) was found from T_0. The highest harvest index (38.57) was found from T_6 (RDF + FYM). The lowest harvest index (35.01 and 35.31) was found in T_3 and T_0.

CONCLUSION

The above result revealed that T_6 (RDF + FYM) treatment gave these highest yield along with higher values in all the growth and yield attributing parameters. It can be said that a higher amount of farm-yard manure along with a recommended dose of fertilizer improved soil properties along with increased availability of essential plant nutrients in the soil. From the result of the experiment, it may be concluded that RDF + FYM application seemed promising for producing a higher yield of Lentil and maintaining soil productivity.

RECOMMENDATIONS

Considering the results of the present experiment, further studies in the following areas are suggested:

- Different levels of organic fertilizer may be used along with different levels of inorganic chemical fertilizer in the Lentil field for getting a variety of specific fertilizer recommendations.
- Similar research could be conducted in other agroecological zones (AEZ) of Bangladesh in order to assess zonal adaptation.

CHAPTER VI

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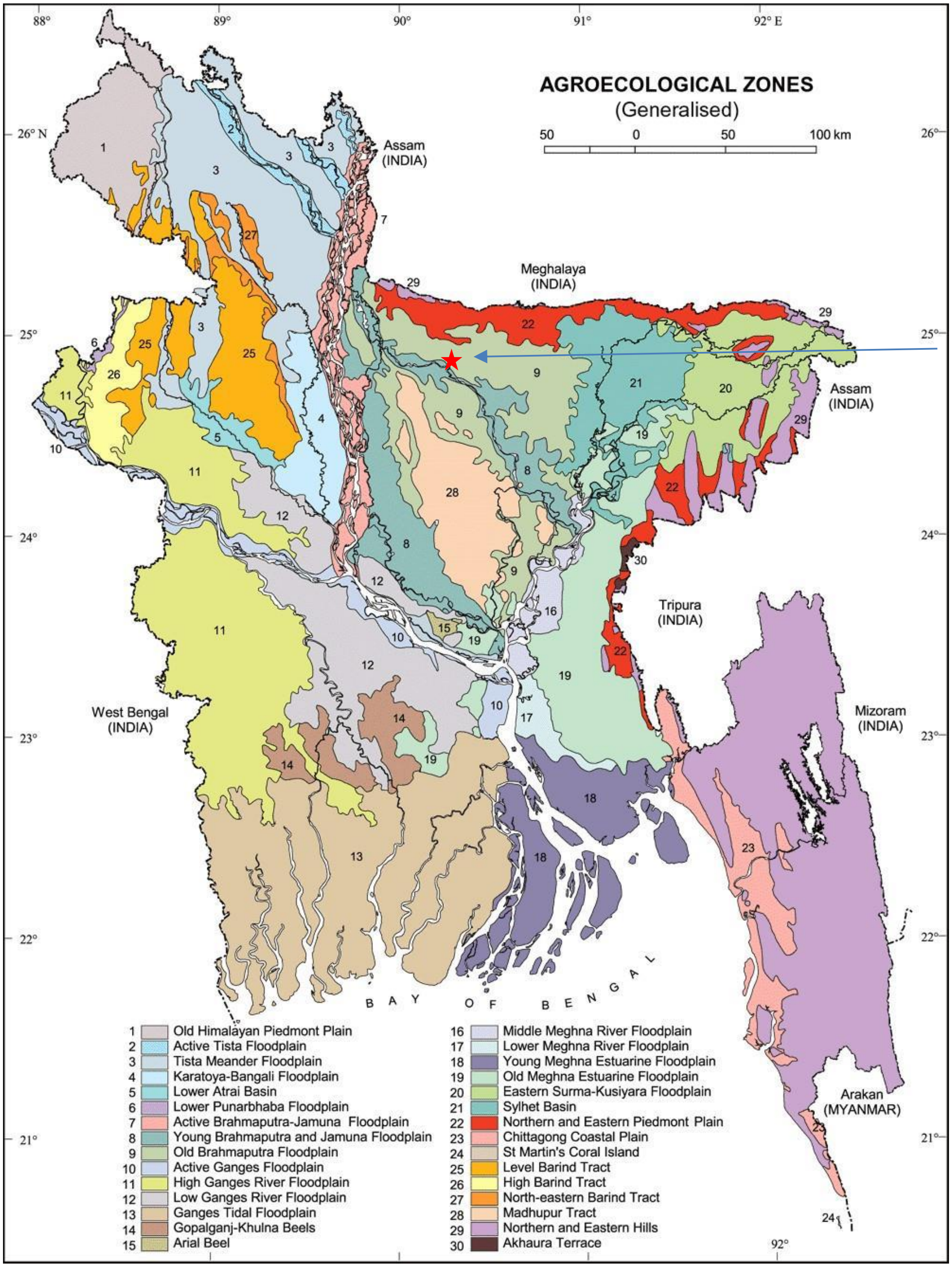
CHAPTER VII

APPENDICES

Appendix I Map showing the experimental site under study



Appendix II Physical characteristics of field soil analyzed in Soil Resources Development Institute (SRDI) laboratory, Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

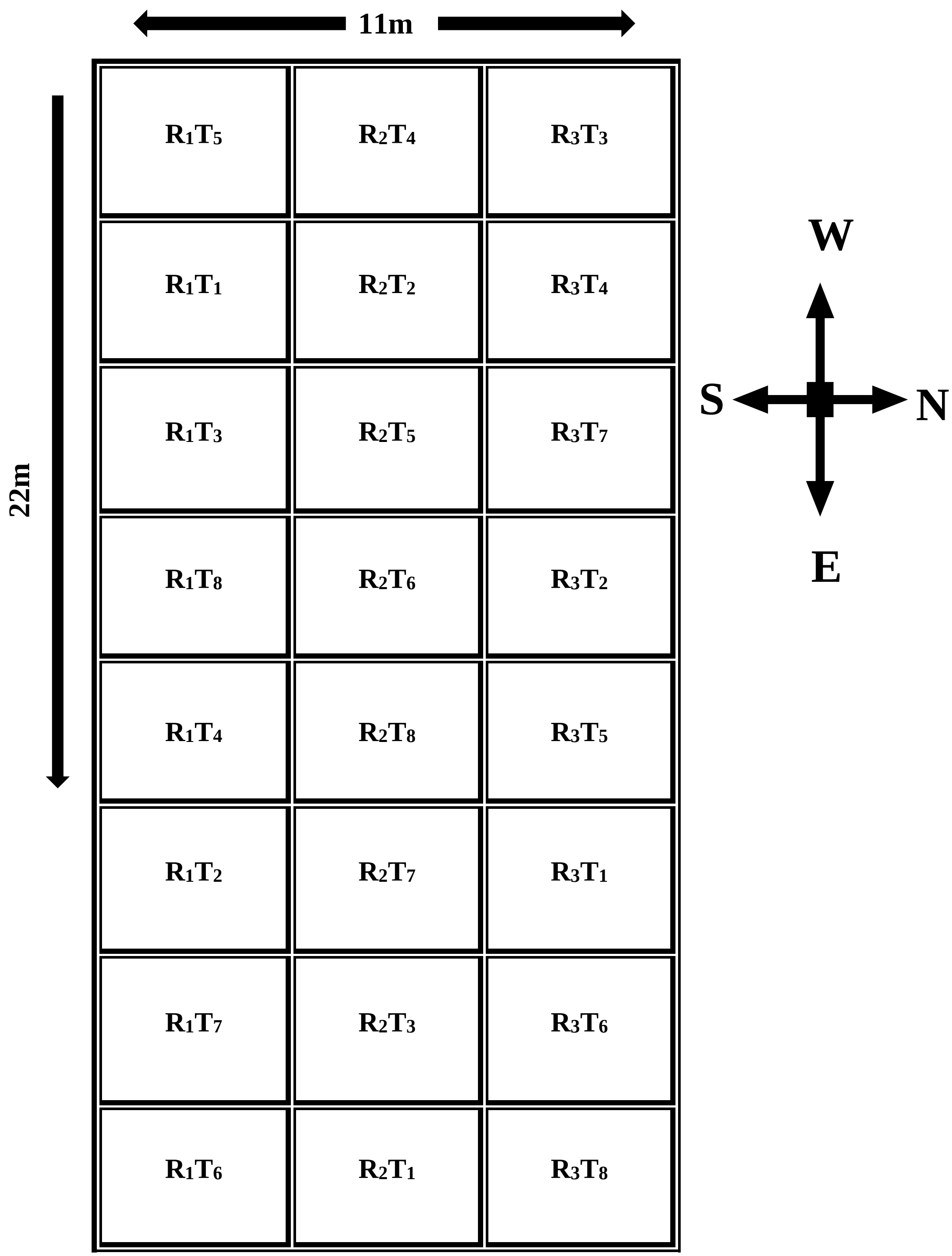
Morphological features	Characteristics
Location	Agronomy field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: Soil Resources Development Institute (SRDI)

Appendix III Field layout of the experimental plot



Appendix IV Monthly record of air temperature, relative humidity, rainfall, and sunshine of the experimental site during the period

Month	*Air temperature (ºc)		*Relative humidity (%)	Total Rainfall (mm)	*Sunshine (hr)
	Maximum	Minimum			
June 2021	22.4	13.5	74	00	6.3
July 2021	24.5	12.4	68	00	5.7
August 2021	27.1	16.7	67	30	6.7
September 2021	31.4	19.6	54	11	8.2
Oct - November 2021	34.2	23.4	61	112	8.1
December 2021	34.7	25.9	70	185	7.8

* Monthly average, Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka – 1212.

Appendix V Means square values for plant height of Lentil at different growth duration

Sources of variation	Degrees of freedom	Mean square		
		30 DAT	60 DAT	90 DAT
Replication	2	0.00196	0.00635	0.0254
Treatment	7	1.89447	6.13808	24.5523
Error (b)	14	0.00575	0.01862	0.0745

* Significant at 5% level; NS = Non significant

Appendix VI Means square values for branch plant^{-1} of Lentil at different growth duration

Sources of variation	Degrees of freedom	Mean square		
		30 DAT	60 DAT	90 DAT
Replication	2	0.11542	0.72135	1.03875
Treatment	7	1.04089	6.50558	9.36804
Error (b)	14	0.03732	0.23326	0.33589

* Significant at 5% level; NS = Non significant

Appendix VII Means square values for nodule number plant^{-1} of Lentil at different growth duration

Sources of variation	Degrees of freedom	Mean square			
		50 DAT	60 DAT	70 DAT	80 DAT
Replication	2	1.22792	2.0752	4.6692	2.6264
Treatment	7	6.96262	11.7668	26.4754	14.8924
Error (b)	14	0.06744	0.1140	0.2564	0.1442

* Significant at 5% level;   NS = Non significant

Appendix VIII Means square values for dry-weight plant^{-1} of Lentil at different growth duration

Sources of variation	Degrees of freedom	Mean square		
		30 DAT	60 DAT	90 DAT
Replication	2	0.00335	0.16404	0.5315
Treatment	7	0.10280	5.03736	16.3211
Error (b)	14	0.00099	0.04843	0.1569

* Significant at 5% level;   NS = Non significant

Appendix IX Means square values for the yield of Lentil at different growth duration

Sources of variation	Degrees of freedom	Mean square				
		Weight of 1000 seeds (g)	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	2.5013	0.01017	0.02795	0.01571	6.77020
Treatment	7	10.7457	0.21963	0.90713	1.99917	3.88493
Error	14	0.1787	0.00170	0.00314	0.00540	0.53820

* Significant at 5% level; NS = Non significant