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PERFORMANCE OF DIFFERENT BIOFERTILIZER ON YIELD OF ONION UNDER MADHUPUR TRACT

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ABSTRACT

The experiment was conducted in research field of the Soil Science Division of the Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, during the Rabi seasons of 2023-2024 and 2024-2025 to determine the effects of various biofertilizer inoculations and varying N and P fertilizer dosages on onion yield. Nine treatments and four replications made up the Randomized Complete Block design of the trial. The test crop was Onions (BARI piaj-4). This experiment used an inoculum of *Azotobacter*, phosphate-solubilizing bacteria (PSB), and *Arbuscular mycorrhiza* (AM). Nine treatments namely, T_1: 100% NPKSZn of RD (Recommended Dose), T_2: 80% N + *Azotobacter* inoculum, T_3: 80% P + *PSB* inoculum, T_4: 50% P + *AM* inoculum, T_5: 80% NP +*Azotobacter + PSB*, T_6: 80% N+ 50% P +*Azotobacter+ AM*, T_7: 50% P + *AM+PSB*, T_8: 80% N+ 50% P + *Azotobacter +AM+PSB and* T_9: Control. During 2023-24, the results of the experiment revealed that the maximum bulb yield of onion (21.25 t ha^{-1}) was found in T_6 (80% N+ 50% P +*Azot. + AM*) treatment which was statistically identical with T_3, T_4, T_5, T_1 and T_8 treatments. The similar trends of results were observed during 2024-25. This result indicated that the application of *Azotobacter* and AM inoculum along with reduced dose of N and P fertilizer was beneficial for production of onion in the Grey Terrace soils of Gazipur (AEZ 28) and it could reduce 20% of nitrogenous and 50% of phosphatic fertilizer.

Keywords: Azotobacter, Phosphate Solubilizing Bacteria, *Arbuscular Mycorrhiza*, Bulb yield, Nitrogenous fertilizer, Phosphatic fertilizer

1 INTRODUCTION

The onion (*Allium cepa* L.) is widely used as a vegetable, condiment, and flavoring agent. This species has been recognized as a spice with nutritional and health value. It is one of the most important spice crops of Bangladesh, which plays a vital role in the national food system, household nutrition, and agricultural economy. Onion bulbs contain vitamin C, dietary fibre, flavonoids, particularly quercetin and its derivatives, and sulfur-containing compounds that contribute to antioxidant activity. According to Bangladesh Bureau of Statistics, onion occupied approximately 426,157 acres of land and produced about 1.80 million metric tons in Bangladesh during 2018-2019 (BBS, 2019). Increasing population, changing food preferences and growing demand for spices have consequently increased the need for sustainable improvement of onion productivity.

Nutrient management is one of the major factors determining onion growth, bulb development and yield. Onion has a relatively high nutrient requirement, and adequate supplies of nitrogen (N), phosphorus (P), potassium and other essential nutrients are necessary for optimum bulb production. In conventional production systems, crop nutrient requirements are frequently met through mineral fertilizers. Although chemical fertilizers are essential for maintaining crop productivity, excessive or imbalanced application may contribute to nutrient losses, soil degradation and environmental pollution. In particular, phosphorus applied to agricultural soils can become rapidly immobilized, resulting in relatively low fertilizer-use efficiency, while excess nutrients may contribute to environmental problems (López-Arredondo et al., 2014). Therefore, integrated nutrient management strategies that combine mineral fertilizers with beneficial microorganisms are increasingly important for maintaining productivity while improving nutrient-use efficiency.

Biofertilizers containing beneficial microorganisms can complement mineral fertilizers by improving nutrient availability, stimulating plant growth and enhancing biological processes in the rhizosphere. Among the important plant-growth-promoting microorganisms, *Azotobacter* has considerable potential because of its ability to fix atmospheric nitrogen and produce biologically active compounds that can stimulate plant growth. Research on onion has demonstrated that inoculation with plant-growth-promoting rhizobacteria, including *Azotobacter chroococcum*, can improve plant growth and yield under field conditions (Colo et al., 2014). More recent research has likewise demonstrated beneficial effects of *Azotobacter* on onion growth, yield and soil fertility when integrated with organic nutrient sources (Ali et al., 2025).

Phosphate solubilizing bacteria (PSB) are another class of beneficial microorganisms that play a major role in improving the availability of P to crops. A significant amount of phosphate fertilizer that is applied to the soil becomes unavailable to plants due to various processes that take place in the ground. These bacteria can help mobilize less available phosphate and thus improve the ability of plants in terms of nutrition. Their combined use with mineral fertilizers can increase the productivity of onions and the assimilation of nutrients. One of the recent field experiments with microbial inoculants in onions showed that using PSB could improve the growth of plants and their ability to absorb nutrients, especially when used in combination with mineral fertilization (Arunachalam et al., 2024).

Arbuscular mycorrhizal (AM) fungi are also essential components of sustainable nutrient management. They are able to associate symbiotically with plant roots and extend their hyphal network into the surrounding soil, thus increasing the soil volume explored by roots. This is especially important for the acquisition of relatively immobile nutrients such as phosphorus. The AM pathway can help P uptake from soil beyond the immediate nutrient-depletion zone surrounding roots and can contribute to plant nutrient acquisition and growth (Smith et al., 2011; Smith and Smith, 2012). The effectiveness of AM fungi, however, can vary according to the plant genotype, fungal species or inoculum, soil fertility and environmental conditions. Consequently, field evaluation under specific agroecological conditions is essential before recommending microbial inoculants as components of fertilizer-management strategies.

The combined application of beneficial microorganisms with reduced rates of mineral fertilizers may provide an effective approach to enhance fertilizer use efficiency while maintaining crop productivity. Earlier research has reported favorable responses of onion to the combined application of chemical fertilizers and biofertilizers. For instance, the combined application of Azotobacter and PSB along with reduced mineral fertilizer rates has been reported to maintain or improve onion productivity over conventional fertilizer management practices (Yadav et al., 2012). Likewise, recent field studies have shown that microbial inoculation can affect onion growth, nutrient uptake and productivity under various fertilizer regimes, though responses were not always consistent across environments and treatment combinations (Arunachalam et al., 2024). These findings suggest that appropriate combinations of microbial inoculants and mineral fertilizers need to be considered in relation to local soil and climatic conditions.

The Grey Terrace soils of the Madhupur Tract (especially Gazipur, AEZ 28) represent a major production environment where efficient nutrient management is key to sustaining crop productivity. However, scant information is available on the combined effects of Azotobacter, PSB and AM inoculation with reduced N and P fertilizer rates for onion production

under this soil condition. Therefore, the present study was conducted during the Rabi seasons of 2023-2024 and 2024-2025 at the research field of the Soil Science Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, to evaluate the performance of different biofertilizer combinations along with reduced N and P fertilizer rates on the growth and yield of onion (Allium cepa L. cv. BARI Piaj-4). The particular emphasis was given to identify a suitable combination of Azotobacter, PSB and AM inoculants which could maintain or improve the bulb yield while reducing the use of mineral N and P fertilizers.

2 MATERIALS AND METHODS

2.1 Seedling collection and final land preparation

The study was conducted in the Rabi season of 2023-2024 and 2024-2025 at the research field of the Soil Science Division, BARI, Joydebpur, Gazipur located in the Madhupur tract (24.00° N latitude, 90.25° E longitude, and 8.4 m elevation). Onion seedlings (BARI piaj-4) were cultivated on a seed bed within the net house of the Soil Science Division, BARI, Joydebpur, Gazipur. The sandy clay loam soils collected from the banks of the Turag River at Kodda, Gazipur were utilized in the seed bed. Cow dung was applied at 1 kg m^{-2} in the seedbed. The pH level of cow dung measured 6.7, with nutrient compositions being: organic matter 14.1%, N 0.8%, P 1.26%, K 0.88%, Ca 1.55%, Mg 0.82%, S 0.62%, Fe 0.25%, and Mn 0.112%. Table 1a shows the physical and chemical characteristics of the initial soil, while Table 1b displays the status of the initial microbial population.

Table 1a: Initial fertility status of the study plot

Soil Properties	Texture	pH	OM (%)	Ca	Mg	K	Total N (%)	P	S	B	Cu	Fe	Mn	Zn
				meq 100 g^{-1}				µg g^{-1}						
Result	Silty clay loam	6.05	1.32	15.7	0.86	0.16	0.10	1.9	14.56	0.69	5.38	151.3	54.21	4.22
Critical level	-	-	-	2.0	0.5	0.12	-	10	10	0.2	0.2	4.0	1.0	0.60

Table 1b: Microbial population status of initial soil and different organic manures

Materials	Population (cfu/g)					
	Rhizobia	PSB	Azotobacter	Fungus	Actinomycetes	Total bacteria
Initial soil	3.0×105	1.6×106	1.0×106	5.0×106	6.5×105	1.7×107

2.2 Analysis of Soil and Organic Fertilizer

Soil pH was assessed using a combined glass calomel electrode (Jackson, 1958). Organic carbon was measured using the Wet Oxidation Method (Walkley and Black, 1934). Total N was measured using the modified Kjeldahl method (Jackson, 1962). Calcium, K, and Mg were measured using the NH_4OAc extraction technique (Black, 1965). Cu, Fe, Mn, and Zn were measured using DTPA extraction and subsequently analyzed by AAS. Boron was identified through the $CaCl_2$ extraction technique. Phosphorus was measured using the Modified Olsen method (Neutral + Calcareous soils) as outlined by Olsen et al. (1954). Sulphur was measured through the extraction of $CaH_4(PO4)_2.H_2O$, followed by the turbidimetric turbidity method using $BaCl_2$.

2.3 Application of fertilizer and organic manure

Chemical fertilizers were administered at a rate of 100 kg N ha^{-1} from urea, 55 kg P ha^{-1} from TSP, 75 kg K ha^{-1} from MoP, 22 kg S ha^{-1} from gypsum, and 5 kg Zn ha^{-1} from ZnSO4 for onions (FRG, 2018). During final land preparation, all other fertilizers were treated as basal, with the exception of urea-N and two thirds of MoP, which were administered as two equal splits and three equal splits, respectively.

2.4 Azotobacter inoculum preparation

A normal microbiological process was used to prepare the Azotobacter inoculum. On slants of Jensen's N-free media (Jensen 1951), azotobzcter strains were injected. N-free Jensen's medium was used to subculture the slants (Jensen 1951). A conical flux holding Jensen's N-free broth was used to inoculate a pure culture of Azotobacter from the subculture plate (Jensen 1951). For three to four days, the broth was shaken in a horizontal shaker to allow for enough bacterial cell development. The plate count dilution method was used to measure bacterial growth. The broth was utilized as an Azotobacter inoculum once the bacteria had grown properly. For two to three hours, the onion seedling was submerged in the liquid inoculum. The seedlings were soaked and then placed in the field.

2.5 Phosphate Solubilizing Bacterial (PSB) inoculum preparation

A normal microbiological process was used to prepare the phosphate-solubilizing bacterial inoculum. Slants of Pikovaskya agar medium (Pikovaskya, 1948) were infected with PSB strains. Pikovaskya agar medium was used to subculture the slants (Pikovaskya 1948). A conical flux containing Pikovaskya broth was used to inoculate a pure culture of Azotobacter from the subculture plate (Pikovaskya 1948). For three to four days, the broth was shaken in a horizontal shaker to allow for enough bacterial cell development. The plate count dilution method was used to measure bacterial growth. The broth was utilized as an Azotobacter inoculum once the bacteria had grown properly. For two to three hours, the onion seedling was submerged in the liquid inoculum. The seedlings were soaked and then placed in the field.

2.6 Preparing onion seedlings infected with arbuscular mycorrhiza

In order to produce mycorrhiza-infected onion seedlings during seedling raising in the seedbed, soil containing mycorrhiza spores and infected sorghum roots was utilized as a mycorrhiza inoculum. At a rate of 100 g per square meter, a thin layer of mycorrhiza inoculum was applied directly beneath the onion seeds.

2.7 Treatments and experiment design

Nine treatments and four replications were used in the RCBD design of the trial. T_1: 100% NPKSZn of RD (Recommended Dose), T_2: 80% N + Azotobacter inoculum, T_3: 80% P + PSB inoculum, T_4: 50% P + AM inoculum, T_5: 80% NP + Azotobacter + PSB, T_6: 80% N + 50% P + Azot., T_7: 50% P + AM+PSB, T80% N + 50% P + AM+PSB, and T_9: Control. For every treatment, a blanket dose of KSZn was administered.

2.8 Transplanting seedlings

Healthy onion seedlings (BARI piaj-4) were gathered from the soil science division's net house and seed bed at BARI, Joydebpur, Gazipur. In the soil science division's experimental field at BARI, Joydebpur, Gazipur, a four-square-meter (2 m × 2 m) plot was created. Following the preparation of the experimental plot, seedlings were moved at a distance of 25 cm by 10 cm. Onion seedlings were moved on December 18, 2023, in 2023-2024, December 19, 2024, and in 2024-2025.

2.9 Cross-cultural operations

Watering, weeding, controlling insect pests, and other intercultural tasks were carried out as needed. MoP fertilizer and urea top dressing were applied on time.

2.10 Harvesting crops

After 45 days following transplanting, five onion plants from each plot were gathered in order to record several growth parameters, such as plant height, number of leaves per plant, shoot weight, and root weight. Onions were harvested in 2023-2024 on March 23 and in 2024-2025 on March 27. Plant height, individual bulb weight, bulb height, bulb diameter, and bulb yield plot-1 were among the parameters that were noted.

2.11 Data analysis

STATISTIX-10 software was used to perform an analysis of variance (ANOVA) on all experimental data. The Least Significant Difference (LSD) test was used to separate and compare treatment means.

3 RESULTS

3.1 Effect of several biofertilizers on onion yield and yield characteristics

Tables 2 and 3 show how various combinations of N, P, and biofertilizers affected onion development, yield characteristics, and bulb yield in 2023-2024 and 2024-2025. Plant height, number of leaves plant^{-1}, bulb diameter, bulb weight, and bulb production all showed significant treatment effects, however the degree of response varied by season.

Plant heights in 2023-2024 varied from 47.65 to 62.60 cm. T_7 (50% P + AM + PSB) had the tallest plants (62.60 cm), which was statistically comparable to T_1, T_3, T_4, T_5, and T_8. The shortest plants (47.65 cm) were produced by the control (T_9). Plant heights in 2024-2025 varied from 38.05 cm in T9 to 49.60 cm in T_6. As a result, T_6 consistently yielded the tallest plants.

In 2023-2024, plant heights ranged from 47.65 to 62.60 cm. The tallest plants (62.60 cm) were found in T_7 (50% P + AM + PSB), which was statistically similar to T_1, T_3, T_4, T_5 and T_8. The control (T_9) generated the shortest plants (47.65 cm). In 2024-2025, plant heights ranged from 38.05 cm in T_9 to 49.60 cm in T_6. T_6 thus regularly produced the tallest plants.

In 2023-2024, T_6 generated the greatest bulb weight (77.42 g bulb^{-1}), and in 2024-2025, T_6 produced the highest bulb weight (53.70 g bulb^{-1}). In both years, the control bulb weight was the lowest. These results suggest that bulb development can be enhanced by the right mix of microbial inoculants and reduced mineral fertilizer.

Table 2: Effect of different biofertilizers on yield and yield attributes of onion in 2023-2024

Treatment	Plant height (cm)	No. of leaves (plant^{-1})	Bulb Diameter (cm)	Bulb wt (g bulb^{-1})	Bulb yield (t ha^{-1})
T_1 : 100% NPKSZn of RD	59.5 ab	8.77bc	5.19a	76.75a	18.81abc
T_2 : 80% N + *Azotobacter inoculum*	58.75bc	9.98a	5.12a	74.97a	17.87bc
T_3 : 80% P + *PSB inoculum*	58.83ab	9.53bc	5.15a	72.00a	18.44abc
T_4 : 50% P + *AM inoculum*	58.90ab	8.73bc	5.33a	75.70a	19.81ab
T_5 : 80% NP +*Azotobacter + PSB*	60.30ab	8.15c	5.23a	75.30a	18.75abc
T_6 : 80% N+ 50% P +*Azot.+AM*	57.88b	8.87bc	5.03a	77.42a	21.25a
T_7 : 50% P + *AM+PSB*	62.60a	8.78bc	5.12a	73.97a	18.37abc
T_8 : 80% N+ 50% P + Azot. +*AM+PSB*	58.68ab	8.62bc	5.22a	76.32a	20.44ab
T_9 : Control	47.65c	6.67d	4.37b	56.42b	13.81d
SE (±)	1.52	0.34	0.06	4.16	1.01
F test	**	**	*	**	**
CV (%)	5.23	8.03	6.35	11.37	11.07

Table 3: Effect of different biofertilizers on yield and yield attributes of onion in 2024-2025

Treatment	Plant height (cm)	No. of leaves (plant^{-1})	Bulb Diameter (cm)	Bulb wt (g bulb^{-1})	Bulb yield (t ha^{-1})
T_1 : 100% NPKSZn of RD	47.68	7.29a	4.22ab	49.00a	14.69b
T_2 : 80% N + *Azotobacter inoculum*	48.08a	7.17a	4.09b	46.10a	16.56ab
T_3 : 80% P + *PSB inoculum*	48.60a	7.14a	4.17ab	46.80a	14.50b
T_4 : 50% P + *AM inoculum*	46.98a	7.25a	4.34ab	51.20a	14.00b
T_5 : 80% NP +*Azotobacter + PSB*	46.80a	6.75a	4.16ab	49.10a	16.38ab
T_6 : 80% N+ 50% P +*Azot.+AM*	49.60a	7.33a	4.52a	53.70a	17.44a
T_7 : 50% P + *AM+PSB*	48.88a	6.75a	4.35ab	50.10a	16.13ab
T_8 : 80% N+ 50% P + Azot. +*AM+PSB*	48.68a	6.75a	4.10ab	48.60a	16.25ab

T_9 : Control	38.05b	5.63b	3.56c	37.30b	10.19c
SE (±)	2.21	0.44	0.21	3.69	1.31
F test	**	*	**	*	**
CV (%)	6.66	9.12	7.00	10.89	12.26

Bulb yield was shown to be the most significant response. T_6 (80% N + 50% P + Azotobacter + AM) had the highest yield (21.25 t ha^{-1}) in 2023-2024, followed by T_8 (20.44 t ha^{-1}) and T_4 (19.81 t ha^{-1}). T_6 shared significant similarities with T_1, T_3, T_4, T_5, and T_8. T_6 (80% N + 50% P + Azotobacter + AM) likewise produced the best yield (17.44 t ha^{-1}) in 2024-2025, which was statistically comparable to T_2, T_5, T_7, and T_8. In the same seasons, the control yielded the lowest amounts (13.81 and 10.19 t ha^{-1}). T_6 raised yield by almost 53.9% in 2023-2024 and 71.1% in 2024-2025 when compared to the control.

3.2 Effect of various biofertilizers on soil characteristics after harvest

The post-harvest soil characteristics of onion-growing soil in the Madhupur Tract varied significantly depending on the biofertilizer treatments applied (Table 4a). After harvest, the pH of the soil rose from 6.05 to 6.50-6.90, with T_4 having the highest value (6.90) and T_2 having the lowest (6.50). The amount of organic matter in the soil rose from 1.32% to 1.55-2.18 %, with T_4 having the highest amount (2.18%).

Table 4a: Effect of different biofertilizers on post-harvest soil properties

Treatment	pH	OM %	Ca	Mg	Total N %	P	S	B	Cu	Fe	Mn	Zn
			meq/100 ml			ppm						
Initial soil	6.05	1.32	15.7	0.86	0.10	1.9	14.56	0.69	5.38	151.3	54.21	4.22
T_1	6.59	1.62	10.56	0.81	0.08	35.7	21.80	0.34	2.70	47.48	20.21	2.63
T_2	6.50	1.62	12.50	0.83	0.08	65.2	30.80	0.32	3.81	80.49	30.21	3.12
T_3	6.65	1.80	11.95	0.82	0.09	81.0	35.00	0.31	3.32	58.35	20.71	2.91
T_4	6.90	2.18	12.43	0.83	0.11	42.5	24.81	0.29	3.56	61.67	20.69	3.31
T_5	6.56	1.80	12.84	0.84	0.09	56.0	24.61	0.32	3.83	73.58	25.98	3.16
T_6	6.86	1.56	12.06	0.83	0.08	38.8	29.81	0.28	3.35	49.58	20.05	2.59
T_7	6.61	1.80	13.24	0.83	0.09	44.9	26.89	0.34	3.61	61.10	24.99	2.72
T_8	6.63	1.55	12.59	0.83	0.08	53.3	19.73	0.28	3.62	63.99	23.27	2.27
T_9	6.63	1.87	13.06	0.83	0.09	48.8	15.38	0.39	3.59	67.80	27.87	3.36

P increased significantly from 1.90 ppm before harvest to 35.70-81.00 ppm. T_3 had the greatest P concentration (81.00 ppm), followed by T_2 (65.20 ppm).

Additionally, available S rose from 14.56 to 15.38-35.00 ppm, with T_3 having the highest value (35.00 ppm). While Mg fluctuated very little (0.81-0.84 meq/100 ml), exchangeable Ca dropped from 15.70 to 10.56-13.24 meq/100 ml, potentially reflecting crop uptake and nutrient cycling. The range of total N was 0.08-0.11%, with T_4 having the highest value (0.11%). T_9 had the highest levels of B and Zn, T_5 had the highest levels of Cu, and T_2 had the highest levels of Fe and Mn among micronutrients.

3.3 Effect of various biofertilizers on post-harvest soil microbial populations

The microbial community of post-harvest soil under onion production in the Madhupur Tract was significantly impacted by the use of several biofertilizer treatments (Table 4b). The rhizobial population varied from 3.0×10^2 CFU g^{-1} in the original soil to 5.0×10^1 CFU g^{-1} in T_8 and 1.5×10 ◦ CFU g^{-1} in T_6 and T_7. T_7 and T_8 had the greatest PSB population (1.0×10^2 CFU g^{-1}), followed by T_3 (9.5×10^2 CFU g^{-1}), suggesting that phosphate-solubilizing bacteria were proliferating under these treatments.

Table 4b: Microbial population of onion post-harvest soil

Treatment	Population (cfu/g)					
	Rhizobia	PSB	Azotobacter	Fungus	Actinomycetes	Total Bacteria
Initial soil	3.0×10^5	1.6×10^6	1.0×10^6	5.0×10^6	6.5×10^5	1.7×10^7
T_1	5.0×10^5	1.5×10^5	9.0×10^5	1.0×10^7	1.5×10^7	4.5×10^7
T_2	1.5×10^5	5.0×10^6	9.0×10^5	3.0×10^6	5.5×10^6	1.5×10^9
T_3	2.5×10^5	9.5×10^6	2.4×10^6	2.5×10^7	2.5×10^7	3.0×10^8
T_4	1.5×10^5	1.6×10^6	3.5×10^6	1.6×10^7	2.0×10^7	1.5×10^7
T_5	3.5×10^5	3.0×10^6	5.0×10^6	3.0×10^5	2.0×10^7	2.0×10^9
T_6	1.5×10^6	4.5×10^6	1.0×10^7	1.0×10^7	3.5×10^7	3.0×10^8
T_7	1.5×10^6	1.0×10^7	7.0×10^6	2.3×10^8	2.0×10^7	2.5×10^8
T_8	5.0×10^4	1.0×10^7	5.0×10^6	1.0×10^7	1.0×10^7	5.0×10^8
T_9	2.0×10^5	1.0×10^7	5.0×10^6	2.5×10^6	2.5×10^7	2.5×10^8

The initial population of Azotobacter was 1.0×10^1 CFU g^{-1}, however it fluctuated from 9.0×10^1 CFU g^{-1} in T_1 and T_2 to 1.0×10^1 CFU g^{-1} in T_6. The fungal population grew significantly in a number of treatments, from 5.0×10^2 CFU g^{-1} at the beginning to 2.5×10^2 CFU g^{-1} in T_3. T_6 had the highest concentration of actinomycetes (3.5×10^2 CFU g^{-1}). When compared to the original 1.7×10^2 CFU g^{-1}, the total bacterial population showed the largest rise in T_5 (2.0×10。 CFU g^{-1}), followed by T_2 (1.5×10。 CFU g^{-1}).

3.4 Effect of different biofertilizers on nutrient content of Onion shoot

Table 5: Nutrient content of Onion Shoot

Treatment	Ca	Mg	K	Na	P	S	Cu	Fe	Mn	Zn	B
	%						ppm				
T_1	5.52	1.68	2.04	0.32	0.52	0.99	2.3	1215	55.1	61	67
T_2	4.44	1.28	2.12	0.33	0.79	0.73	3.6	1089	58.3	65	41
T_3	4.40	1.32	3.00	0.34	0.80	0.74	2.3	1292	99.8	75	52
T_4	3.44	1.12	2.32	0.33	0.44	0.5	1.8	1268	94.6	66	38
T_5	4.40	1.32	1.80	0.32	0.32	0.34	3.8	890	59.1	52	34
T_6	4.20	1.24	2.32	0.34	0.27	0.65	2.7	1095	70.9	67	58
T_7	4.24	1.28	1.96	0.33	0.28	0.48	1.9	1088	69.0	65	52
T_8	4.12	1.24	1.64	0.32	0.30	0.88	3.0	1044	78.6	66	41
T_9	4.72	1.36	2.12	0.33	0.46	0.99	3.1	931	60.2	61	66

T_3 had the highest concentration of phosphorus (0.80%), followed by T_2 (0.79%), while T_6 had the lowest (0.27%). T_1 and T_9 have the highest concentrations of sulfur (0.99%), followed by T_8 (0.88%).

Table 5 shows that the nutrient composition of onion shoots differed significantly between the biofertilizer treatments, indicating variations in nutrient uptake and use. The concentration of calcium varied from 3.44% in T_4 to 5.52% in T_1, but the concentration of magnesium varied from 1.12% in T_4 to 1.68% in T_1. T_3 had the highest K concentration (3.00%), followed by T_4 and T_6 (2.32%), indicating that these treatments improved K acquisition.

Fe concentrations among micronutrients ranged from 890 ppm (T_5) to 1292 ppm (T_3), with T_3 exhibiting the greatest Fe accumulation. While Zn ranged from 52 to 75 ppm, with T_3 having the highest concentration, Mn had the highest concentration (99.8 ppm). T_1 has the highest concentration of boron (67 ppm), followed by T_9 (66 ppm). T_5 had the highest value of copper, which varied from 1.8 to 3.8 ppm.

3.5 Effect of different biofertilizers on onion bulb nutritional content

Onion bulb nutrient content changed significantly between biofertilizer treatments (Table 6), suggesting variable nutrient transport and uptake. The percentage of calcium changed from 2.52% in T_3 to 6.00% in T_8, whereas the concentration of magnesium varied from 0.68% in T_3 to 1.84% in T_6. T_1 and T_9 had the highest K concentration (2.32%), followed by T_7 (2.00%). T_3 has the highest percentage of phosphorus (0.95%), followed by T_2 and T_5 (0.91%). T_6 had the highest sulfur content (0.98%), whereas T_2 had the lowest (0.49%).

Table 6: Nutrient content of Onion Bulb

Treatment	Ca	Mg	K	Na	P	S	Cu	Fe	Mn	Zn	B
	%						ppm				
T_1	2.64	0.76	2.32	0.34	0.82	0.68	1.7	649	51.1	56	94
T_2	2.56	0.72	1.76	0.38	0.91	0.49	1.2	756	46.5	43	33
T_3	2.52	0.68	1.64	0.33	0.95	0.44	0.3	666	38.1	51	42
T_4	3.48	1.04	1.68	0.35	0.50	0.84	0.7	804	28.8	48	39
T_5	4.84	1.52	1.68	0.33	0.91	0.66	2.1	1008	38.8	46	45
T_6	5.56	1.84	1.80	0.33	0.53	0.98	0.4	910	36.8	48	29
T_7	4.68	1.64	2.00	0.34	0.51	0.74	1.7	934	40.6	45	34
T_8	6.00	1.76	1.68	0.34	0.37	0.48	0.8	803	53.6	39	51
T_9	5.32	1.52	2.32	0.35	0.48	0.78	2.9	1234	56.0	41	52

Among micronutrients, T9 recorded the highest Fe (1234 ppm) and Cu (2.9 ppm), while T8 showed the highest Mn (56.0 ppm) and T1 recorded the highest B (94 ppm). Zn concentration varied from 39-56 ppm, with the highest value in T1 and T9 (56 and 52 ppm, respectively).

4 DISCUSSION

The present study demonstrated that biofertilizer application, particularly in combination with reduced rates of mineral N and P fertilizers, improved onion growth, bulb development and yield under the Grey Terrace soils of Gazipur (AEZ 28). Significant treatment effects were observed for plant height, number of leaves plant^{-1}, bulb diameter, bulb weight and bulb yield, although the magnitude of response varied between seasons. The most consistent response was obtained with T_6 (80% N + 50% P + *Azotobacter* + AM), which produced the highest bulb yield in both 2023-24 (21.25 t ha^{-1}) and 2024-25 (17.44 t ha^{-1}), representing increases of approximately 53.9% and 71.1%, respectively, over the unfertilized control.

The improved vegetative growth and bulb development under biofertilizer treatments may be associated with complementary functions of beneficial microorganisms. *Azotobacter* can contribute to biological nitrogen fixation and plant-growth promotion, whereas phosphate-solubilizing bacteria (PSB) increase the availability of poorly soluble phosphorus. AM fungi can further enhance nutrient acquisition by increasing the effective soil volume explored by the root system. Such complementary mechanisms may explain the superior performance of treatments containing AM, PSB and *Azotobacter*. A recent field study on onion similarly demonstrated that PSB and mycorrhizal inoculation could improve plant growth, nutrient uptake and productivity and potentially reduce dependence on mineral fertilizers (Arunachalam et al., 2024).

Because T_6 only used 80% of the necessary N and 50% of the recommended P with microbial inoculants, its excellent performance is very significant. T_6 consistently generated the highest bulb weight and bulb yield in both seasons, while the control group regularly recorded the lowest numbers. This implies that lower supplies of mineral fertilizer may be partially offset by microbial inoculation. Biofertilizers can increase crop productivity and nutrient-use efficiency through mechanisms like biological N fixation, P solubilization, and improved nutrient acquisition, according to a global meta-analysis; however, the degree of response varies depending on soil and environmental conditions (Schutz et al., 2018).

The post-harvest soil results validate PSB's contribution. After harvest, available P increased significantly from 1.90 ppm in the original soil to 35.70-81.00 ppm, with T_3 showing the greatest concentration (81.00 ppm). Additionally, T_7 and T_8 had exceptionally high PSB populations (1.0×10^2 CFU g^{-1}), followed by T_3 (9.5×10^1 CFU g^{-1}). Through processes

involving organic acid synthesis and phosphatase activity, phosphate-solubilizing bacteria can mobilize weakly accessible P, expanding the pool of plant-available P (Khan et al., 2007). The significance of PSB in converting insoluble soil P into forms that plants can use and increasing P-use efficiency is further highlighted by more recent studies (Sun et al., 2026).

The changes in soil microbial populations provide further evidence of enhanced biological activity under several biofertilizer treatments. The Azotobacter population reached 1.0×10^7 CFU g^{-1} in T_6 compared with 1.0×10^6 CFU g^{-1} in the initial soil, while fungal and actinomycete populations reached 2.5×10^7 and 3.5×10^7 CFU g^{-1}, respectively, under selected treatments. Total bacterial population was particularly high in T_5 (2.0×10^9 CFU g^{-1}). These changes indicate that biofertilizer application can stimulate beneficial microbial communities and biological activity in the soil-root environment. Such microbial activity can contribute to nutrient cycling and nutrient-use efficiency, consistent with the broader findings of Schutz et al. (2018).

Additional proof of increased biological activity under various biofertilizer treatments is provided by the alterations in soil microbial populations. Under specific treatments, the fungal and actinomycete populations reached 2.5×10^2 and 3.5×10^1 CFU g^{-1}, respectively, whereas the Azotobacter population reached 1.0×10^2 CFU g^{-1} in T6 compared to 1.0×10^1 CFU g^{-1} in the original soil. T_5 had an especially high total bacterial population (2.0×10^1 CFU g^{-1}). These alterations suggest that the application of biofertilizer can promote biological activity and beneficial microbial communities in the soil-root environment. In line with the more general conclusions of Schutz et al. (2018), such microbial activity can support nutrient cycling and nutrient-use efficiency.

The nutritional makeup of onion bulbs and shoots provides more evidence for the function of microbial inoculation in nutrient translocation and acquisition. While the bulbs had the highest P concentration in T_3 (0.95%), Ca in T_8 (6.00%), Mg in T_6 (1.84%), and S in T_6 (0.98%), the shoots had the highest K (3.00%), P (0.80%), Fe (1292 ppm), and Mn (99.8 ppm). These variations might be the result of improved root growth, nutrient absorption, and nutrient solubilization linked to helpful microbes. While K is involved in physiological processes including photosynthetic activity and glucose translocation, nitrogen, P, K, and S are especially crucial for onion vegetative growth, bulb development, and nutrient accumulation. Because onions have a relatively high S demand and accumulate sulfur-containing compounds, the relatively high S accumulation is also significant.

The current study clearly showed seasonal fluctuation in treatment response. For instance, T_6 generated the tallest plants in 2024-2025, whereas T_7 produced the tallest plants in 2023-2024; similarly, the treatment with the most leaves varied with season. This variance suggests that seasonal and soil variables, including as nutrient availability and microbial establishment, can affect the effectiveness of biofertilizers. However, in both years, T_6 consistently produced the highest bulb weight and yield, suggesting a somewhat stable response under the experimental conditions. This supports research showing that soil characteristics, climate, and nutrient availability can all affect how effective microbial inoculants are (Schutz et al., 2018).

Overall, the results show that onion productivity, nutrient uptake, and biological activity in the Gray Terrace soils of Gazipur can be enhanced by combining biofertilizers with lower N and P fertilizer rates. The potential of microbial inoculants as a crucial part of more nutrient-efficient onion production systems is demonstrated by the constant performance of T_6 (80% N + 50% P + Azotobacter + AM), as well as improvements in microbial populations and nutrient availability under various treatments. These findings are in line with recent studies on onions that demonstrate how microbial inoculation, especially with PSB and mycorrhizal microorganisms, can improve plant growth, nutrient uptake, and yield while offering chances to lessen dependency on mineral fertilizers (Arunachalam et al., 2024).

5 CONCLUSION

The study showed that onion productivity and soil biological fertility under the Gray Terrace soils of the Madhupur Tract are enhanced by biofertilizer inoculation along with lower N and P fertilizer rates. T_6 (80% N + 50% P + Azotobacter + AM) was the treatment that yielded the most bulbs (21.25 t ha^{-1}) in 2023-2024 and continued to do so in 2024-2025. Microbial inoculants have the ability to partially replace mineral fertilizers because their efficacy was statistically equivalent with a number of other integrated treatments. In addition to enhancing specific soil fertility metrics like organic matter, P, and S, the application of biofertilizer increased soil microbial populations, especially beneficial bacterial, fungal, and actinomycete groups. Improved nutrient uptake under particular biofertilizer combinations was further demonstrated by nutrient buildup in onion shoots and bulbs. Overall, the findings indicate that combining AM and Azotobacter with lower N and P fertilizer rates is a viable strategy for sustainable onion production, with the potential to lower N and P fertilizer requirements by about 20% and 50%, respectively, without sacrificing yield.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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The authors declare no conflicts of interest regarding this manuscript.

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