



Effect of Biofertilizer and Mineral Fertilizer Application on Maize Growth and Yield

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Abstract

Maize (*Zea mays L.*) is an important cereal crop whose production is dependent on proper nutrition management. While the combined use of microbial and mineral fertilizers has recently gained importance, field research on particular biofertilizer combinations remains limited. This study involves a field trial assessing the combined use of NPK Consortia, Zinc solubilizing bacteria and mineral fertilizer in maize farming. This experiment was conducted during the 2020–2021 Kharif season at Himatnagar, Gujarat. This study used a split-plot design with six treatments and three replications. The combined application of 50% NPK Consortia and 50% mineral fertilizers (T5) performed considerably more effectively than the control and other treatments. T5 resulted in marked improvements in growth traits, including a 49.7% increase in plant height and a 105.3% increase in stem girth by 60 days after sowing. Yield attributes also improved notably, with T5 achieving the longest ear length (21.8 cm), highest kernel number per ear (615.7), and maximum grain yield (1881.5 kg/ha), demonstrating a 46.1% increase in total yield over the control. These results indicate that combining mineral fertilizers and biofertilizers can enhance crop performance while reducing reliance on chemical fertilizers. The study supports the adoption of microbial consortia-based fertilization strategies for sustainable maize production.

Keywords: BioNPK; Zinc; Maize; Mineral Fertilizer; Sustainable

Introduction

Maize (*Zea mays L.*) is one of the most widely cultivated and economically important cereal crops globally, serving as a cornerstone of food, feed, and industrial systems [1]. It is vital to both commercial and subsistence agriculture because of its high production, diversity in use, and adaptability to a variety of agroecological zones [2]. Maize is rich in carbohydrates and provides a moderate level of protein, serving as a vital source of energy and nutrition, making it a staple food in many countries [3]. In addition to its critical role in human and animal nutrition, maize is a primary industrial raw material used in the production of high-fructose corn syrup, bioethanol, bioplastics, starch-based adhesives, and fermentation products [4].

To meet the increasing demand for higher maize yields, modern agriculture has heavily relied on chemical fertilizers, particularly nitrogen (N), phosphorus (P), and potassium (K) [5]. However, the widespread and excessive use of chemical fertilizers has resulted in a number of agronomic and environmental issues. Such overuse disrupts nutrient balance, reduces nutrient use efficiency, alters soil pH (leading to increased acidity or alkalinity), depletes organic matter, and suppresses the activity of beneficial soil microbial communities [6].

In response to these limitations, biofertilizer formulations containing beneficial microorganisms have emerged as a promising alternative for sustainable crop production [7]. For instance,

nitrogen-fixing bacteria like *Azotobacter* and *Herbaspirillum* convert atmospheric nitrogen into ammonia [8], while phosphate- and potassium-solubilizing bacteria such as *Bacillus megaterium*, *Pseudomonas fluorescens* [9], and *Frateuria aurantia* mobilize essential nutrients from insoluble soil forms through the secretion of organic acids and enzymes [10].

Micronutrients like zinc (Zn), though required in smaller amounts, play a crucial role in enzymatic activity, chlorophyll synthesis, membrane stability, and auxin production [11]. Zinc deficiency is widespread in maize-growing regions, especially in alkaline soils, and leads to stunted growth, reduced grain yield, and lower nutritional quality [12]. Zinc-solubilizing bacteria, primarily *Bacillus* and *Pseudomonas* strains, enhance Zn availability by secreting organic acids, chelators, and siderophores [13].

The application of microbial consortia targeting both macro- and micronutrient deficiencies represents an integrated and sustainable approach to nutrient management [14]. Biofertilizer formulations, such as NPK Consortia and Zinc-enriched products, contain diverse microbial strains that work together to mobilize essential nutrients, improve nutrient uptake by plants, and enhance microbial activity in the soil. This synergistic interaction contributes to better soil fertility and increased crop productivity through improved nutrient cycling and plant health [15].

While mineral fertilizers provide rapid nutrient availability and immediate crop response, increasing evidence shows that biofertilizers alone can achieve comparable plant growth, nutrient uptake, and yield, especially over the long term [16]. However, in nutrient-poor soils or critical growth stages, mineral fertilizers remain necessary; integrating them with biofertilizers ensures more efficient nutrient use and minimizes environmental impacts [17].

Despite increasing interest in the use of biofertilizers, field-based research on the combined application of specific microbial consortia with mineral fertilizers in maize cultivation remains limited. The present study evaluates the individual and integrated effects of NPK Consortia and Zinc with mineral fertilizers on maize growth, nutrient uptake, and yield under field conditions.

Although the use of biofertilizers is increasingly promoted in sustainable agriculture, field-based research assessing their

combined use with mineral fertilizers in maize cultivation remains limited. This study examines the individual and combined effects of NPK Consortia and Zinc, when applied in conjunction with mineral fertilizers, on maize growth, nutrient uptake, and yield under field conditions, to advance commercial nutrient management strategies to enhance crop productivity.

Materials and Methods

Experimental site and duration

The field experiment was conducted at the experimental farm located in Himatnagar, Gujarat, during the Kharif season of 2020–2021.

Experimental design

The experiment followed a split-plot layout based on a randomized complete block design (RCBD) with three replications. Six treatment combinations were tested to evaluate the individual and combined effects of microbial NPK consortia containing *Azotobacter chroococcum* (N) NCBI Accession number PZ246100, *Pseudomonas putida* (P), NCBI Accession number PZ246135, *Frateuria aurantia* (K) NCBI Accession number PZ246123, Zinc solubilizing bacteria *Cytobacillus firmus* NCBI Accession number PZ246121, and mineral fertilizers on maize growth and yield. The treatments were as follows in Table 1.

Treatments	Treatment Details
T1	Control (no biofertilizer or mineral fertilizer): 0%
T2	100% NPK Consortia
T3	100% Zinc Solubilizing bacteria
T4	50% NPK Consortia + 50% Zinc
T5	50% NPK Consortia + 50% Mineral Fertilizer (at recommended dose)
T6	50% Zinc Solubilizing bacteria + 50% Mineral Fertilizer (at recommended dose)

Table 1: Description of treatments applied in the study

The recommended fertilizer dosage (RDF) for maize was 120:60:40 kg/ha of N: P₂O₅: K₂O and applied using conventional chemical sources: urea (46% N), single super phosphate (16% P₂O₅), and potash muriate (60% K₂O).

Biofertilizer application and crop management

Biofertilizers were used as both seed treatments and supplements to the soil. Before planting, seeds were treated with 5 mL per kilogram. At 3 and 5 WAS, the appropriate biofertilizers were also applied to the field at a rate of 250 ml per acre. Maize was manually seeded in 2.4 m × 4 m (9.6 m²) plots with an intra-row spacing of 20 cm.

Data collection on growth and yield parameters

Plant growth and yield data were recorded at 15, 30, 45, and 60 days after sowing, as well as at harvest. The recorded parameters included: plant height (cm), stem girth (cm), leaf area (cm²), root length (cm), root dry weight (g), shoot dry weight (g), root-to-shoot dry weight ratio, cob length (cm), number of rows per cob, number of grains per cob, 1000-grain weight (g), and grain yield (kg/ha).

Leaf area was calculated using the formula:

$$\text{Leaf Area} = \text{Leaf Length} \times \text{Leaf Width} \times 0.7,$$

As per the method described by Li, *et al.* (2007) [18]. Biomass samples (root and shoot) were dried at 60°C in an oven until constant weight and measured using a digital weighing balance.

Grain yield was estimated following the formula of Sapkota, *et al.* (2016) [19]:

Grain yield (kg/ha) =

$$\frac{\text{Number of kernels per row} \times \text{Number of ears per m}^2}{100} \times \frac{1000 - \text{kernel weight}}{1000} \times 10,000$$

Statistical analysis

All collected data were subjected to Analysis of Variance (ANOVA). The differences among treatment means were evaluated using the Least Significant Difference (LSD) test at a 5% level of significance, following the procedure outlined by Gomez and Gomez (1984) [20].

Results and Discussion

Growth parameters

Plant height

The application of biofertilizers, mineral fertilizers, and their combinations significantly influenced maize plant height

throughout the growth stages (15, 30, 45, and 60 DAS). A significant increase was observed in T5 (301 ± 15), which received 50% NPK Consortia + 50% mineral fertilizer, indicating better growth productivity than the control (201 ± 12). This showed that T5 was comparatively more effective, followed by T6 (279 ± 11) (50% Zinc + 50% mineral fertilizer) and T4 (270 ± 9) (50% NPK Consortia + 50% Zinc) (Figure 1). Similarly, the combination of *Azotobacter* inoculation, nitrogen, and farmyard manure (FYM) led to a substantial increase in maize plant height, which reached 213 cm as compared to 186 cm in the control [21]. The treatment involving 100% biofertilizer, comprising a microbial consortium of *Azospirillum*, *Azotobacter*, *Rhizobium*, and *Bacillus spp.*, in combination with 75% of the recommended dose of NPK, resulted in a maize plant height of 97.35 cm at eight weeks after sowing, indicating a positive synergistic effect on vegetative growth [22].

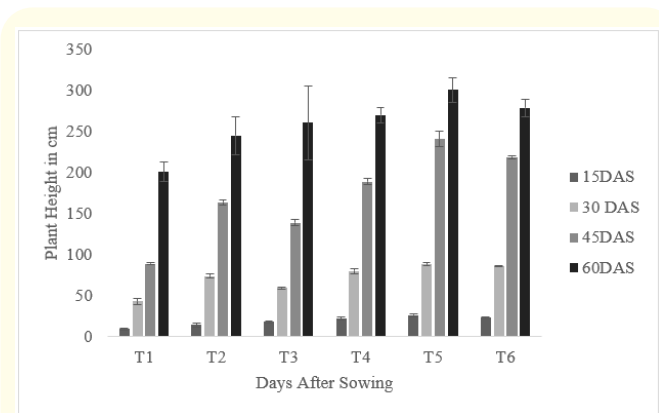


Figure 1: Effect of NPK Consortia, Zinc, and mineral fertilizers on the plant height of maize.

Stem girth

Stem girth progressively increased across growth stages, with the highest value recorded in T5 (3.9 ± 0.2 cm) at 60 DAS. This was substantially higher than the control (1.9 ± 0.1 cm), indicating improved stem robustness. T4 (3.1 ± 0.3 cm) and T6 (2.7 ± 0.1 cm) also exhibited considerable increases (Figure 2). Several studies have demonstrated that integrated nutrient management practices can considerably enhance stem girth in maize compared to conventional methods. The largest stem girth in maize, measuring 24.92 mm, was obtained using an integrated nutrient management technique incorporating 75% biofertilizer and 50% mineral fertilizer, indicating the benefits of mixing organic and inorganic supplies [23]. Similarly, a treatment comprising

50% NPK, 25% farmyard manure (FYM), and 25% vermicompost recorded a stem girth of 12.3 cm for maize, higher than the control, which measured only 7.09 cm [24].

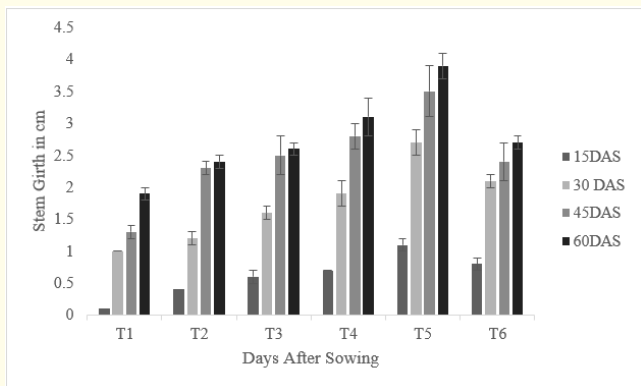


Figure 2: Effect of NPK Consortia, Zinc, and mineral fertilizers on the stem girth of maize.

Leaf area

Leaf area showed consistent growth over time, with clear differences by 60 DAS. The largest leaf area was observed in T5 (1406 ± 23 cm²), T6 (1358 ± 16 cm²), and T4 (1244 ± 12 cm²). In contrast, the control had a considerably smaller leaf area (957 ± 11 cm²) (Figure 3). Furthermore, the use of microbial biofertilizer consortia led to a substantial enhancement in maize leaf area, which increased to 995 cm² compared to 529 cm² in the control, reflecting better nutrient absorption and vegetative growth [25]. The integrated use of vermicompost, poultry manure, *Azotobacter*, and phosphate-solubilizing bacteria (PSB) led to the greatest leaf area in maize plants, compared to the control and other nutrient treatments [26].

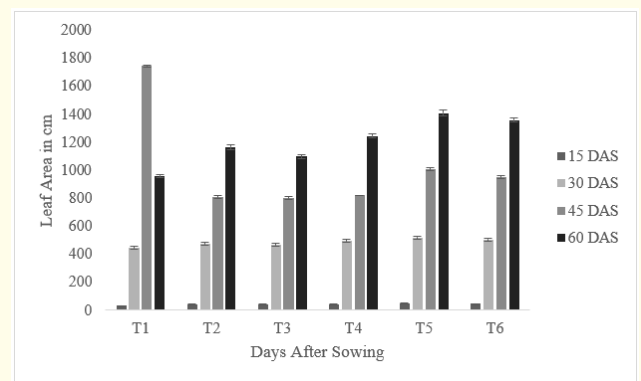


Figure 3: Effect of NPK Consortia, Zinc, and mineral fertilizers on the leaf area of maize.

Root length

In root length, T5 showed the highest root growth, reaching 39 ± 2 cm at 60 DAS. This was significantly higher than the control, which recorded only 26 ± 1 cm. T6 (36 ± 2 cm) and T4 (34 ± 2 cm) also performed better than the control (Figure 4). Improvement in maize root development has been widely associated with the combined use of nutrient supplements and microbial inputs. The foliar application of phosphorus and potassium, along with microbial biostimulants, considerably enhanced root traits, resulting in a 33% increase in root length density and a 48% increase in root dry biomass within the top 0–20 cm soil layer

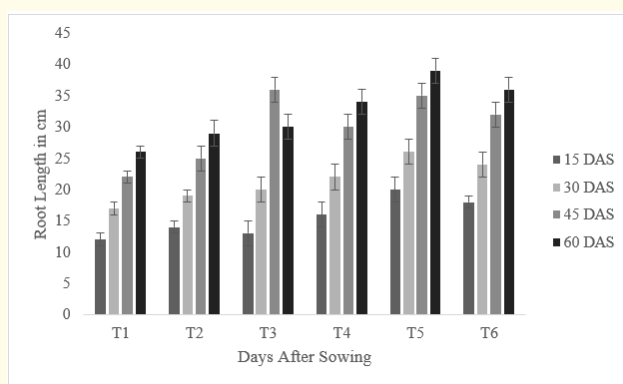


Figure 4: Effect of NPK Consortia, Zinc, and mineral fertilizers on root length of maize.

compared to the control [27]. Moreover, *Azospirillum* inoculation notably increased root length to 31.85 cm, in contrast to 25 cm observed in the uninoculated control, demonstrating its role in stimulating root growth [28].

Root dry weight

The highest root dry weight was recorded in T5 (25.1 ± 0.5 g), which was substantially higher than the control (12.5 ± 0.3 g). T6 (21.0 ± 0.8 g) and T4 (15.6 ± 0.4 g) also showed higher root biomass compared to the control (Figure 5). Additionally, previous studies have reported that the application of 50% NPK biofertilizers in maize significantly increased root dry weight to 16.9 ± 0.3 g [29].

Shoot dry weight

The combination of biofertilizers and mineral fertilizers showed a substantial effect on maize shoot dry weight. The shoot

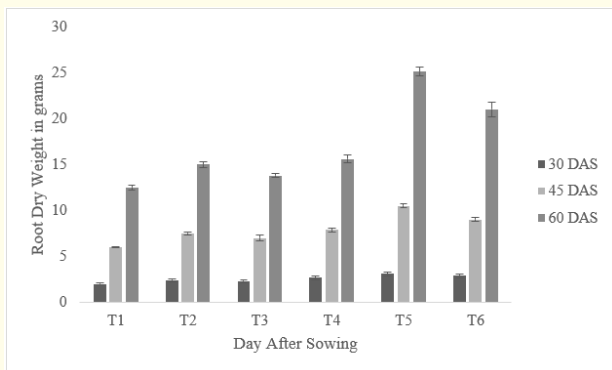


Figure 5: Effect of NPK Consortia, Zinc, and mineral fertilizers on root dry weight of maize.

weight increased with treatment. T5 had the highest dry weight at 130.2 g, while T6 (128.5 g) and T4 (112.7 g) also showed good results compared to the control (78.1 g) (Figure 6). Furthermore, shoot dry weight in maize has shown considerable improvement under integrated nutrient management practices. In one study, the combined application of 50% recommended NPK and biofertilizer resulted in a shoot dry weight of 138.09 g, indicating enhanced biomass production through improved nutrient uptake and microbial activity [30]. Likewise, another field experiment reported a shoot dry weight of 16.43 g per plant in maize treated with composted press-mud and recommended NPK fertilizers, compared to 9.4 g in the untreated control, demonstrating the effectiveness of organic-inorganic nutrient combinations in promoting shoot growth [31].

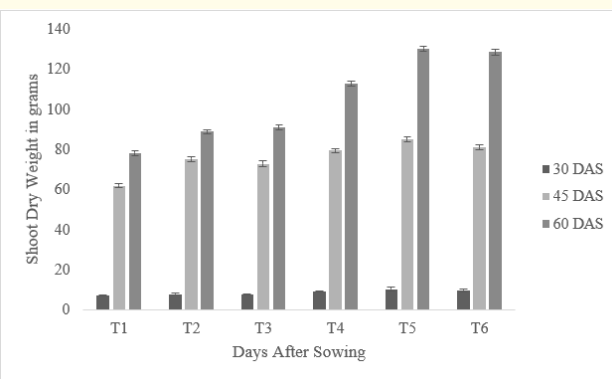


Figure 6: Effect of NPK Consortia, Zinc, and chemical fertilizers on the shoot dry weight of maize.

In terms of plant height, stem girth, leaf area, root development, and biomass accumulation, the T5 treatment (50% NPK Consortia + 50% Mineral Fertilizer) produced the most beneficial result.

Yield parameters

Ear length

Analysis of ear length indicated that the application of T5 (50% NPK Consortia + 50% Mineral Fertilizer) resulted in the highest ear length (21.8 cm), T6 (50% Zinc + 50% mineral fertilizer) with 18.3 cm, and T4 (50% NPK Consortia + 50% Zinc) with 20.2 cm, while the shortest ear length was observed under the control treatment T1 (no fertilizer), with 10.03 cm (Table 2). Further research indicated that increasing the application of farmyard manure (FYM) from 10 to 20 mg/ha led to a noticeable improvement in ear length in maize, with measurements rising from 15.5 cm at the lower rate to 17 cm at the higher level [32]. The longest ear length in maize was obtained at 20.32 cm in the first season and 20.50 cm in the second season, which were recorded in a field trial that combined 75% NPK with growth enhancers and biofertilizers [33].

Number of rows per ear

Table 2 showed that the maximum number of rows per ear was observed in treatment T5 (15.7), followed by T6 (14.6), T4 (14), and T2 (12.7). Whereas the minimum value was recorded under the control treatment T1 (10.5). In another study, maize plants treated with 18 t/ha of liquid bio slurry and 46 kg N/ha produced 14.4 grain rows per ear, compared to just 9.5 in untreated plants. The various NPK fertilizer levels found that the highest NPK dose (250:110:85 kg/ha) produced the maximum grain rows per cob (15.30), whereas the lowest dose resulted in 13.53 rows per ear in maize [35].

Number of kernels per row and per ear

The number of kernels per row was highest in T5, with an average of 45.0, compared to just 30.2 in the control. Similarly, the total number of kernels per ear is also higher in T5 at 615.7, while the control had only 396.4 (Table 2). In maize, the application of biofertilizers (*Azotobacter*) in combination with 6 t/ha vermicompost and 50% mineral fertilizer substantially improved kernel growth, yielding up to 48.1 kernels per row and 763.2 kernels per ear [36]. The incorporation of 50% nitrogen at sowing and during the first irrigation (T₁ treatment) resulted in a kernel

count of 501.7 per ear in 2019 and 512.3 per ear in 2020, indicating the effectiveness of split nitrogen application in enhancing maize reproductive performance [37].

1000-Kernel weight

The highest 1000-kernel weight was recorded under T5 (188.7 g), T6 (182.5 g), and T4 (153.6 g), compared to the control (126.1 g) (Table 2). In a 2019–2020 field experiment on sweet corn (*Zea mays* var. *saccharata*), the integrated use of biofertilizer consortia containing boron and zinc, combined with recommended mineral fertilizers, produced the highest 1000-kernel weight of 198.9 g [38]. Similar field study (2017–18) reported the highest 1000-kernel

weight of 220.3 g in maize under the full recommended dose of fertilizer combined with optimized vermicompost and biofertilizer [39].

Grain yield

Grain yield was highest in T5 at 1881.5 kg/ha, while the control had only 1288.4 kg/ha (Table 2). Additionally, the integrated use of vermicompost (2 t/ha) with 75% of the recommended dose of fertilizer (RDF) and a 0.5% ZnSO₄ foliar spray resulted in a maize grain yield of 9.04 t/ha, which exceeded the yield obtained from 100% RDF alone (8.94 t/ha) [40]. The integration of *Azotobacter* inoculation with 100% NPK and 100% vermicompost was found to be highly effective, resulting in a grain yield of 4.6 t/ha (46 q/ha) [41].

Treatments	Ear Length (cm)	Rows/Ear	Kernels/Row	Kernels/Ear	1000-Kernel Weight (g)	Grain Yield (kg/ha)
T1	10.03 ± 0.6 ^e	10.5 ± 1.1 ^d	30.2 ± 2 ^e	396.4 ± 20.1 ^e	126.1 ± 10.9 ^d	1288.4 ± 121.0 ^e
T2	12.2 ± 1.3 ^d	12.7 ± 1.3 ^c	39.0 ± 2.1 ^c	460.1 ± 14.9 ^c	140.0 ± 18.5 ^c	1525.6 ± 116.7 ^c
T3	16.1 ± 1.4 ^c	12 ± 0.6 ^c	37.5 ± 1.9 ^c	437.9 ± 23.8 ^c	143.3 ± 11 ^c	1508 ± 122.4 ^c
T4	20.2 ± 0.8 ^b	14.0 ± 1.7 ^b	43.4 ± 1.4 ^b	481.2 ± 18.5 ^b	153.6 ± 20.9 ^b	1747.9 ± 140.2 ^b
T5	21.8 ± 1 ^a	15.7 ± 1.1 ^a	45.0 ± 2.7 ^a	615.7 ± 20.8 ^a	188.7 ± 23.9 ^a	1881.5 ± 142.0 ^a
T6	18.3 ± 1.1 ^b	14.6 ± 1.3 ^b	40.2 ± 2 ^b	587.1 ± 21.7 ^a	182.5 ± 12.2 ^a	1769.0 ± 115.1 ^b

Table 2: Impact of biofertilizer and fertilizer combinations on maize productivity.

In terms of growth parameters like ear length, number of rows, kernels per row, total kernels per ear, grain weight, and yield, T5 (NPK Consortia 50% + Mineral Fertilizer 50%) continuously showed the highest results among all treatments.

Conclusion

The present study demonstrated that the combined application of Zinc and NPK Consortia biofertilizers with mineral fertilizers significantly enhanced maize growth and yield attributes. The integrated approach improved nutrient uptake efficiency and promoted better physiological performance, resulting in the value of combining organic and inorganic nutrient sources. Importantly, biofertilizers applied alone also showed notable potential to support crop development, indicating their role as a sustainable and eco-friendly alternative to chemical inputs. These results support the adoption of integrated nutrient management

(INM) strategies to improve crop productivity while reducing environmental impact. However, long-term studies are essential to assess the broader implications of such practices on soil health, microbial communities, and nutrient dynamics across diverse agro-ecological environments.

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