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INFLUENCE OF PLANT GROWTH PROMOTING RHIZOBACTERIA AND NITROGEN LEVELS ON GROWTH, YIELD ATTRIBUTES AND YIELD OF MAIZE (*Zea mays* L.)

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ABSTRACT

A field experiment was conducted during the *kharif* season of 2025 at the Wheat and Maize Research Unit, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, to assess the effect of graded nitrogen levels and plant growth-promoting rhizobacteria (PGPR) on growth and yield of maize (*Zea mays* L.). The experiment was laid out in a randomized block design with eight treatments and three replications. The treatments comprised an absolute control, PGPR alone and 50, 75 and 100% of the recommended dose of nitrogen (RDN), each with and without PGPR. The PGPR consortium consisted of *Azotobacter chroococcum*, *Azospirillum lipoferum* and *Bacillus subtilis* and was applied as a seed treatment. Plant height, leaf area and chlorophyll content were recorded as growth attributes, while cob length, grains cobn[1], test weight, grain yield and straw yield were measured. Growth and yield attributes improved with increasing nitrogen supply, and PGPR application further improved the response at corresponding nitrogen levels. The treatment receiving 100% RDN + PGPR (T_8) recorded the highest values for all measured growth and yield traits. Grain yield increased from 3167 kg ha^{-1} in the absolute control to 5704 kg ha^{-1} under 100% RDN + PGPR, while straw yield increased from 6036.67 to 8750.41 kg ha^{-1}. The results indicate that PGPR inoculation complemented mineral nitrogen fertilization and improved maize growth and yield under the conditions of the experiment.

Key words : Maize, PGPR, Nitrogen, Growth, Yield attributes, *Azotobacter*, *Azospirillum*.

Introduction

Maize (*Zea mays* L.) is an important cereal crop cultivated across a wide range of climatic conditions because of its adaptability and high yield potential. It is used extensively for food, livestock and poultry feed and as a raw material for starch, oil, sweeteners, beverages, biofuel and other industrial products. In India, maize is grown during *kharif*, *rabi* and summer seasons, and Maharashtra is one of the major maize-producing states. With the growing demand for maize from food, feed and processing industries, maintaining high and stable production has become increasingly important.

Nitrogen (N) is a major nutrient determining maize growth and grain production. It is required for the formation of chlorophyll, proteins, enzymes and nucleic acids and consequently affects leaf development, photosynthetic activity and biomass accumulation. Maize generally responds strongly to nitrogen fertilization, particularly when soil nitrogen supply is inadequate. However, increasing the amount of fertilizer N does not necessarily result in a corresponding increase in yield. A substantial fraction of applied N can be lost through leaching, volatilization, runoff and denitrification. Besides reducing fertilizer recovery, these losses increase production costs and may contribute to groundwater

contamination, eutrophication and nitrous oxide emissions. Repeated and unbalanced fertilizer use can also influence soil biological processes and nutrient cycling.

Improving the efficiency with which maize utilizes applied nitrogen is thus as important as increasing the amount of nitrogen supplied. One way of addressing this is to combine mineral fertilizers with beneficial soil microorganisms. The rhizosphere provides an active zone where plant roots interact with microorganisms and soil nutrients. Several microorganisms associated with plant roots can improve nutrient availability, stimulate root growth and influence plant nutrient acquisition through biological processes such as nitrogen fixation, nutrient solubilization and production of growth-regulating substances. Conservation agriculture practices, including reduced soil disturbance, soil-cover maintenance and crop diversification, can contribute to improved soil health, nutrient cycling and sustainable crop production (Hiremath *et al.*, 2026; Richardson *et al.*, 2009; Vacheron *et al.*, 2013).

Plant growth-promoting rhizobacteria (PGPR) are among the microorganisms receiving considerable attention for their role in plant nutrition. These bacteria colonize the root region and influence plant growth through several mechanisms, including biological nitrogen fixation, nutrient solubilization, production of phytohormones and siderophores and suppression of certain soil-borne pathogens. *Azotobacter chroococcum* is a free-living nitrogen-fixing bacterium, while *Azospirillum* forms an association with cereal roots and can contribute to nitrogen acquisition and improved root development. *Bacillus subtilis*, although not primarily a nitrogen-fixing organism, can support plant growth by improving nutrient acquisition and utilization. The combined use of these organisms may provide complementary benefits to the crop.

The response to PGPR inoculation is closely related to the amount of mineral nitrogen available to the crop. When nitrogen supply is low, nitrogen-fixing bacteria may partly supplement the plant's nitrogen requirement. At moderate fertilizer levels, microbial activity may improve nutrient uptake and the utilization of applied nitrogen. The benefit obtained from inoculation may, however, vary with nitrogen supply, soil conditions and the interaction among microorganisms and plant roots. Thus, simply increasing either fertilizer N or microbial inoculation may not be sufficient; the appropriate combination needs to be identified under a given production environment.

Earlier studies have reported beneficial effects of PGPR, particularly *Azospirillum*, on maize growth, yield and nitrogen-use efficiency under different nitrogen regimes (Zeffa *et al.*, 2019; Hungria *et al.*, 2022; Galindo *et al.*, 2022). However, responses can differ with the level of nitrogen applied, microbial composition and field conditions. Information on the performance of a PGPR consortium comprising *Azotobacter chroococcum*, *Azospirillum lipoferum* and *Bacillus subtilis* along with graded nitrogen levels is particularly relevant for identifying an efficient nutrient-management practice for maize. Keeping these considerations in view, the present study was undertaken to evaluate the effect of graded nitrogen levels and PGPR inoculation on growth, yield attributes and yield of maize (*Zea mays* L.).

Materials and Methods

Experimental site and design

A field experiment was conducted during the *kharif* season of 2025 at the Wheat and Maize Research Unit, Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani, Maharashtra, India. The experimental soil was a black clay soil belonging to the Vertisol order. The experiment was laid out in a randomized block design (RBD) comprising eight treatments with three replications, giving a total of 24 experimental plots. Each plot measured 3.6 × 4.0 m. Maize was used as the test crop and sown by dibbling at 60 × 20 cm spacing with a seed rate of 15 kg ha^{-1}.

The initial soil was slightly alkaline in reaction, with a pH of 7.78 and electrical conductivity of 0.48 dS m^{-1}. Soil organic carbon was 4.60 g kg^{-1}, while available nitrogen, phosphorus and potassium were 110.67, 10.20 and 560.00 kg ha^{-1}, respectively. The initial DTPA-extractable Fe, Zn, Mn and Cu contents were 3.10, 0.45, 5.30 and 2.63 mg kg^{-1}, respectively.

Treatments and crop management

The experiment consisted of an absolute control, PGPR alone and three levels of nitrogen with and without

Table 1 : Treatment details of the experiment.

Tr. No.	Symbol	Treatment details
1	T_1	Control (No PGPR, No nitrogen fertilizer)
2	T_2	PGPR application only
3	T_3	50% Recommended dose of nitrogen (RDN) only
4	T_4	PGPR + 50% RDN
5	T_5	75% RDN only
6	T_6	PGPR + 75% RDN
7	T_7	100% RDN only
8	T_8	PGPR + 100% RDN

PGPR. The treatment combinations were as follows:

The recommended fertilizer dose was 120:80:60 kg N: P_2O_5 : K_2O ha^{-1}. Urea, single superphosphate and muriate of potash were used as the sources of nitrogen, phosphorus and potassium, respectively. The PGPR consortium consisted of *Azotobacter chroococcum*, *Azospirillum lipoferum* and *Bacillus subtilis*. The consortium was applied as a seed treatment at the rate of 200 mL per 10 kg of seed. Half of the recommended nitrogen was applied at sowing, while the remaining half was applied one month later. The recommended quantities of phosphorus and potassium were applied at sowing. Other crop-management practices were followed according to the recommended package of practices for maize.

Observations and statistical analysis

Plant height and leaf area were recorded at the tasselling and harvesting stages. Chlorophyll content was measured at 30 and 60 days after sowing using a SPAD meter. Yield attributes, including cob length, number of grains per cob and test weight, were recorded at harvest. Grain yield and straw yield were also determined and expressed in kg ha^{-1}.

The data were analysed using the statistical procedures applicable to a randomized block design. The standard error of the mean [SE(m)] and critical difference (CD) at the 5% level of significance were calculated for comparing treatment means

Results and Discussion

Growth attributes

The growth of maize was influenced by both nitrogen application and PGPR inoculation. Plant height, leaf area and chlorophyll content generally increased with improvement in nitrogen supply, while PGPR addition further improved these parameters. The treatment receiving 100% RDN + PGPR (T_8) recorded the highest values. The observed response is consistent with field evidence that microbial inoculants can enhance maize growth and yield under integrated nutrient management (Adesemoye *et al*., 2008; Santos *et al*., 2020; Vacheron *et al*., 2013).

At tasselling, plant height ranged from 159.41 cm in T_1 to 233.31 cm in T_8; at harvest it ranged from 165.53 to 241.27 cm. Leaf area increased from 403.18 to 577.15 cm² plant^{-1} at tasselling and from 377.85 to 543.77 cm² plant^{-1} at harvest. Chlorophyll readings increased from 27.89 to 45.87 SPAD at 30 DAS and from 35.61 to 52.08 SPAD at 60 DAS. The higher values under T_8 indicate better vegetative development and nitrogen nutrition.

Yield attributes

Cob length increased from 17.38 cm in T_1 to 20.80 cm in T_8. Grains cob^{-1} increased from 369.33 to 616.67, while test weight increased from 17.54 to 22.31 g. The response suggests that adequate nitrogen supply supported reproductive development and grain filling, with PGPR providing an additional benefit at the corresponding nitrogen levels. Similar responses have been reported for maize inoculated with PGPR under different nitrogen regimes (Zeffa *et al*., 2019; Fernandes *et al*., 2020; Galindo *et al*., 2022; Barbosa *et al*., 2022; Cassán & Díaz-Zorita, 2016).

Grain and straw yield

Grain yield increased from 3167.00 kg ha^{-1} in T_1 to 5704.00 kg ha^{-1} in T_8. The 100% RDN treatment without PGPR (T_7) produced 5275.89 kg ha^{-1}, indicating that PGPR provided an additional yield benefit when applied with the recommended nitrogen dose. Straw yield showed a similar trend, increasing from 6036.67 kg ha^{-1} in T_1 to 8750.41 kg ha^{-1} in T_8. The higher grain and straw yields under T_8 were associated with improved plant growth and yield attributes, particularly plant height, leaf area,

Table 2 : Effect of nitrogen levels and PGPR on growth parameters of maize.

Treatment	Plant height (Tasselling)	Plant height (Harvest)	Leaf area (Tasselling)	Leaf area (Harvest)	Chlorophyll (30 DAS)	Chlorophyll (60 DAS)
T_1	159.41	165.53	403.18	377.85	27.89	35.61
T_2	171.64	187.40	439.66	412.17	29.42	40.61
T_3	178.26	193.71	455.58	427.98	31.14	41.18
T_4	192.76	209.19	496.85	464.65	33.88	41.69
T_5	198.27	206.89	509.46	479.57	35.99	42.93
T_6	203.00	211.12	549.27	514.59	38.29	46.67
T_7	206.58	213.40	554.24	520.52	39.42	46.02
T_8	233.31	241.27	577.15	543.77	45.87	52.08
SE(m)±	8.95	9.15	21.72	20.51	1.69	1.68
CD at 5%	25.14	27.75	65.89	62.22	5.14	5.12

Table 3 : Effect of nitrogen levels and PGPR on yield attributes of maize.

Treatment	Cob length (cm)	Grains cob^{-1}	Test weight (g)
T_1	17.38	369.33	17.54
T_2	18.14	471.00	19.00
T_3	18.43	487.00	19.86
T_4	18.61	484.00	20.46
T_5	19.16	524.33	20.87
T_6	19.59	562.00	21.42
T_7	19.83	573.33	21.78
T_8	20.80	616.67	22.31
SE(m) ±	0.92	19.76	0.88
CD at 5%	2.79	59.94	2.68

Table 4 : Effect of nitrogen levels and PGPR on grain and straw yield of maize.

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	3167.00	6036.67
T_2	3770.16	6596.67
T_3	4026.84	7033.33
T_4	4856.76	7203.33
T_5	5053.00	7750.83
T_6	5193.50	8200.64
T_7	5275.89	8350.18
T_8	5704.00	8750.41
SE(m) ±	203.57	310.67
CD at 5%	617.48	940.86

cob length, number of grains per cob and test weight. Similar beneficial effects of combining nitrogen fertilization with PGPR inoculation on maize growth, nitrogen uptake and grain yield have been reported by Di Salvo *et al*. (2018), Galindo *et al*. (2022), Galindo *et al*. (2024), Barbosa *et al*. (2022) and Cassán and Díaz-Zorita (2016). These findings suggest that the combined application of adequate nitrogen and beneficial microorganisms can improve nutrient acquisition and support maize productivity under field conditions.

Conclusion

The application of nitrogen and PGPR inoculation positively influenced the growth, yield attributes and yield of maize. Increasing nitrogen levels improved plant growth and yield performance, while PGPR inoculation provided an additional beneficial effect at the respective nitrogen levels. Among the treatments, 100% RDN + PGPR (T_8) recorded the highest values for plant height, leaf area, chlorophyll content, cob length, number of grains per cob, test weight, grain yield and straw yield. Grain yield increased from 3167.00 kg ha^{-1} in the absolute control to 5704.00 kg ha^{-1} under T_8. These findings indicate that the combined application of the recommended nitrogen dose and PGPR can improve maize productivity.

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