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The economic impact of different levels of NPK fertilizers, micronutrients like Neem cake, and Plant Growth Promoting Rhizobacteria (PGPR) on maize (*Zea mays* L.)

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Abstract
The study entitled "Evaluation of Micronutrient Neem Cake and Plant Growth Promoting Rhizobacteria (PGPR) on Soil Properties and Yield of Maize (*Zea mays* L.)". The research was conducted during the Kharif season of 2016-2017 at the Field Experimentation Centre of the Department of Soil Science, Sam Higginbottom University of Agriculture, Technology and Sciences (formerly Allahabad Agricultural University), Allahabad (U.P), India. During the study, data were collected on 15 different characteristics, and a total of 9 treatments were evaluated, including the control group. Based on the mean performance across all evaluated characteristics, Treatment-8 (consisting of 100% Recommended Dose of Fertilizer (RDF), 100% Neem cake, and Rhizobium at a rate of 200 gm/kg) was identified as the best treatment for promoting plant growth and seed yield. Treatment-8 showed superior results in various aspects, including plant height (cm), pod length (cm), number of pods per plant, number of seed pods per plant, weight of pods at 50 and 75 days after crop maturity, as well as several physical and chemical properties of the soil. These soil properties included particle and bulk density, water holding capacity, porosity percentage, soil colour, and chemical attributes like available nitrogen, phosphorus, potassium, pH of the soil, and electrical conductivity of the soil. The study also found that there was a significant interaction effect of Integrated Nutrient Management for all evaluated characteristics, suggesting that the combination of different nutrients and amendments in the form of Integrated Nutrient Management could have a positive impact on the physical and chemical properties of the soil, ultimately leading to improved economic and yield attributes of maize. In conclusion, the research supports the effectiveness of using micronutrient Neem cake and plant growth promoting Rhizobacteria (PGPR) in combination with the recommended dose of fertilizer (RDF) for enhancing plant growth and seed yield in maize cultivation. Additionally, the findings highlight the potential of Integrated Nutrient Management as a beneficial approach for soil improvement and achieving better economic and yield outcomes for maize crops.

Keywords: N, P, K, Plant growth promoting Rhizobacteria, growth parameters, economics maize

Introduction
Maize (*Zea mays* L.) is a significant cereal crop globally and holds importance as human food, animal feed, fodder, and industrial raw material. It belongs to the Gramineae family and is commonly known as corn. In the world, maize ranks third among food crops, following rice and wheat, while in India, it stands fourth after rice, wheat, and sorghum. In India, maize cultivation covers an area of 8.87 million hectares, with a production of 22.63 million tons and a productivity of 2567 kg per hectare (FAI, 2021-22). In the state of Rajasthan, maize is cultivated in an area of 0.87 million hectares, producing 1.16 million tons with a productivity of 1335 kg per hectare (FAI, 2021-22). Nitrogen is a crucial plant nutrient that significantly influences crop growth, yield, and quality. It is the primary limiting nutrient for plants and plays a vital role in various plant metabolic processes. Nitrogen is an essential component of proteins, nucleic acids, enzymes, ATP, NADH, NADPH, cytochrome, and chlorophyll (Demari *et al*., 2016; Jat *et al*., 2021a) [24]. The application of nitrogen fertilizers is instrumental in enhancing maize production, promoting the growth of nodes, internodes, and increasing plant height, leaf area, number of leaves per plant, and stem diameter.

Nitrogen also positively impacts biomass and grain yield, protein quality in grains, and fodder quality (Meena and Jain, 2013; Demari *et al*., 2016) [11]. Studies have shown that the use of manures improves crop yield, soil organic matter (SOM), and soil quality (Meena *et al*., 2022) [13]. While organic manures provide essential nutrients for plant growth, their production may not be sufficient to meet crop nutrient requirements. Therefore, integrated nutrient management, which involves the combined use of organic and inorganic fertilizers, becomes crucial (Meena *et al*., 2023) [7]. This approach allows farmers to fulfill crop nutrient needs efficiently. Based on the above facts, the present investigation focused on studying various combinations of organic and inorganic nutrient sources and their impact on yield attributes and maize productivity. This research aims to identify the most effective nutrient management practices to enhance maize production and optimize crop yield.

Materials and Methods

A field experiment was conducted during two consecutive years 2016-17 and 2016-17 to assess the effect of different levels of levels of NPK fertilizers. Micronutrients Neem cake, and plant growth promoting Rhizobacteria (PGPR) on maize (*zea mays* L.). A field experiment was conducted at the Instructional farm, Naini agricultural institute, Prayagraj. The site is situated in southern part of Uttar Pradesh at an altitude of 98 m above mean sea level, at 25º45' N latitude and 81º84' E longitude. The mean annual rainfall of the region varies from 1000 to 1100 mm, most of which is received in rainy season from July to September. The mean maximum and minimum temperature are 38.40 °C & 21.70 °C in 2016, respectively. This zone possesses typical sub-tropical climatic conditions characterized by mild winters and moderate summers associated with high relative humidity during the months of July to September. The mean annual rainfall of the region is 1050 mm, most of which is contributed by south west monsoon from July to September. At the initiation of the experiment field was sandy loam in soil texture and pH 7.37, organic carbon 0.51 per cent, medium in available nitrogen (290.62 kg/ha) and phosphorus (22.53 kg/ha) and high in available potassium (156.47 kg/ha). Treatment details are given in table 1 where treatments were analyzed in randomized block design (RBD) with three replications. The experimental data recorded were subjected to statistical analysis using analysis of variance as outlined by Panse and Sukhatme (1985) [17].

Table 1: Treatment details of the experimental sites for *kharif* 2016

Symbol	Treatment details
T_0	Control
T_1	(T_1 = I 0 +N 1) (@ 0% NPK, Zinc + 50% Neem cake and PGPR)
T_2	(T_2 = I 0 +N 2) (@ 0% NPK, Zinc + 100% Neem cake and PGPR)
T_3	(T_3 = I 1 +N 0) (@ 50% NPK, Zinc + 0% Neem cake and PGPR)
T_4	(T_4 = I 1 +N 1) (@ 50% NPK, Zinc + 50% Neem cake and PGPR)
T_5	(T_5 = I 1 +N 2) (@ 50% NPK, Zinc + 100% Neem cake and PGPR)
T_6	(T_6 = I 2 +N 0) (@ 100% NPK, Zinc + 0% Neem cake and PGPR)
T_7	(T_7 = I 2 +N1) (@ 100% NPK, Zinc + 50% Neem cake and PGPR)
T_8	(T_8 = I 2 +N 2) (@ 100% NPK, Zinc + 100% Neem cake and PGPR)

Results and Discussions

Yield and Yield attributes

Soil Properties and Yield of Maize: The one-year data presented in Table 2 showed that different treatments significantly influenced soil properties and the yield of maize, both in terms of grain yield and straw yield, compared to the control treatment. Treatment T_8: Among the treatments, T_8, which involved the application of 100% NPK, 100% Neem cake, 100% PGPR, and Zinc, resulted in the maximum test grain yield of 4460 kg per hectare and the highest stover yield of 6958 kg per hectare during the year 2016. Number of Grains per Cob: Tiwari *et al*. (2017) [22] found that the application of organic manure (Neem cake and PGPR) along with inorganic fertilizer recorded the significantly highest number of grains per cob. Test Weight: The findings of Jha *et al*. (2015) [9] supported the current study, showing that the application of 100% RDF (Recommended Dose of Fertilizer) along with Zinc resulted in the significantly highest test weight of maize. Grain Yield Improvement: Other studies by Meena *et al*. (2017) and Jat *et al*. (2023) [7] also showed that the use of farmyard manure (FYM) in combination with 100% NPK significantly improved grain yield compared to using 100% NPK alone. Stover Yield Improvement: Additionally, Shah *et al*. (2010) [19], Meena *et al*. (2012) [12], and Bhatt *et al*. (2018) [3] reported that the application of FYM along with NPK resulted in a significant improvement in Stover yield. Overall, the results of this study and the findings of previous research indicate that the application of integrated nutrient management practices, such as combining organic manure (e.g., Neem cake, FYM) with inorganic fertilizers (NPK and Zinc), can significantly enhance soil properties and maize productivity. Treatment T_8 with the integration of 100% NPK, 100% Neem cake, 100% PGPR, and Zinc showed the highest grain yield and Stover yield, making it a promising option for improving maize production.

Economics

Gross Return: The highest gross return of 85,232 Rs per hectare was achieved with the application of treatment T_8, which consisted of 100% NPK, 100% Neem cake, 100% PGPR, and Zinc, during the study years. Cost of Cultivation: The maximum cost of cultivation, amounting to 33,413 Rs per hectare, was incurred with the application of treatment T_8 during the study years. Net Return: The highest net return of 51,819 Rs per hectare was obtained with the application of treatment T_8 during the study years. On the other hand, the lowest net return of 25,965.45 Rs per hectare was recorded under the control treatment T_0 during the study years. Benefit-Cost Ratio: The benefit-cost ratio (B:C ratio) is a measure of profitability. It indicates how many rupees of benefits are generated per rupee of cost invested in a particular treatment. Higher B:C ratios indicate more economically viable options. The application of treatment T_8 (100% NPK + 100% Neem cake + 100% PGPR and Zinc ha^{-1}) recorded the highest B:C ratio of 1:2.55 during the year 2016. Treatments T_7, T_6, T_5, and T_4 also showed significantly increased B:C ratios compared to the control (T_0) during the year 2016 and in the overall mean. The lowest B:C ratio of 1:2.05 was observed with the application of the control treatment T0 during the year 2016. Overall, the results suggest that treatment T_8

(100% NPK + 100% Neem cake + 100% PGPR and Zinc) performed well in terms of gross return, net return, and benefit-cost ratio. It showed the highest economic profitability among the treatments studied. Additionally, treatments involving organic–inorganic source amendments generally demonstrated better economic viability compared to the control treatment throughout the study period.

Table 2: Evaluation of different benefit cost ratio (B:C) of different treatment combination with integrated nutrients of maize

Treatment	Grain yield q ha^{-1}	Straw yield q ha^{-1}	Gross return	Cost of cultivation	Net return	C:B ratio
T_0	26.33	41.5	50465.45	24500	25965.45	1:2.05
T_1	30.05	42.7	55963.25	25910	30053.25	1:2.15
T_2	31.46	49.78	60365.90	27320	33045.90	1:2.20
T_3	33.84	52.78	64664.60	27546.5	37118.10	1:2.34
T_4	36.62	55.65	69463.80	29034.5	40429.30	1:2.39
T_5	38.66	58.69	73312.40	30411.5	42900.90	1:2.41
T_6	41.08	59.67	74228.70	30593	43635.70	1:2.42
T_7	42.39	64.25	80273.85	32003	48270.85	1:2.50
T_8	44.60	69.58	85232	33413	51819	1:2.55

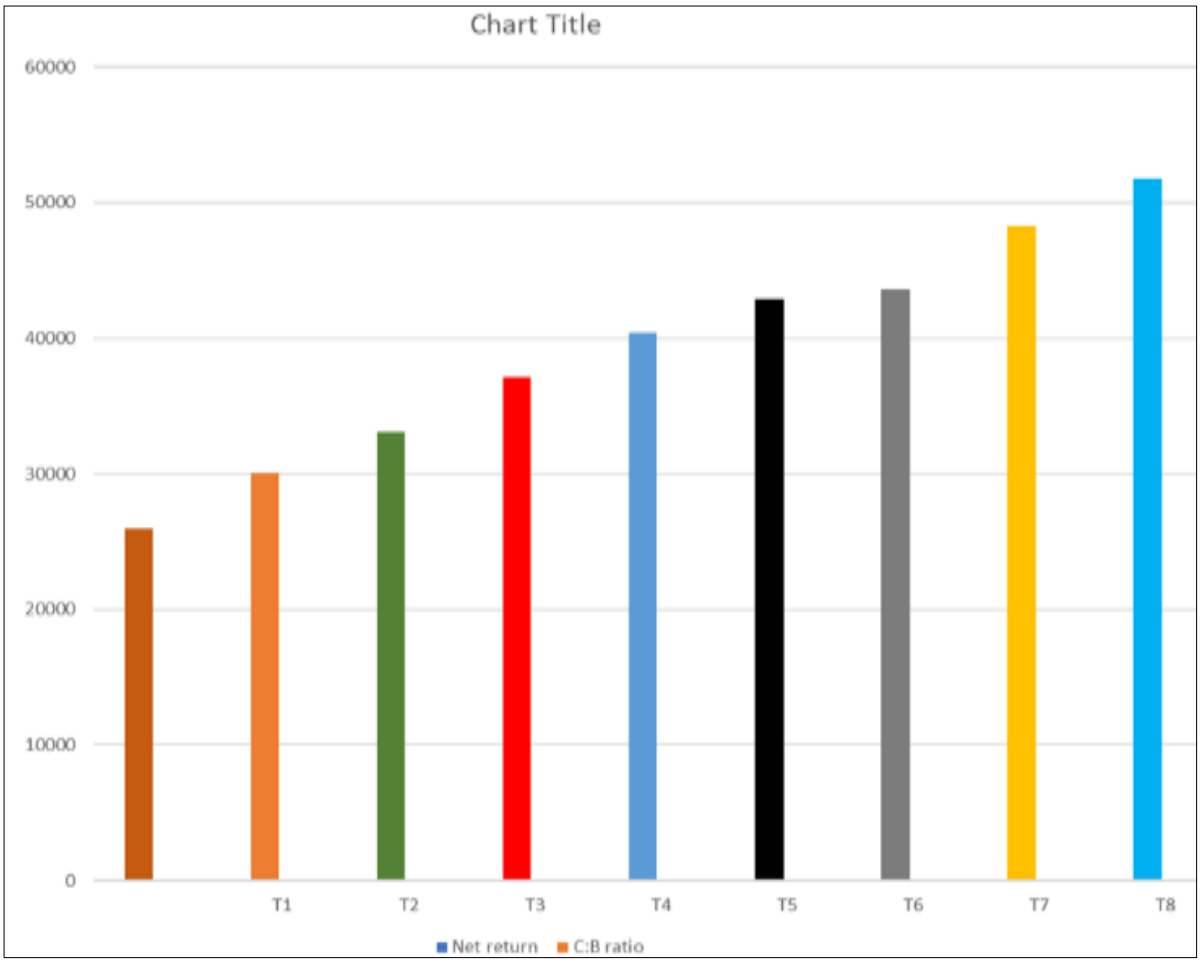

Fig 1: To evaluate the B:C ratio for different treatment combinations with integrated nutrients of maize

Conclusion

When chemical fertilizers are used in conjunction with Neem cake and biofertilizer, it results in significant improvements in various aspects. One of the benefits is the restoration of soil organic carbon and nutrient turnover, which enhances the availability of nutrients in the soil. This, in turn, contributes to maintaining soil quality and promoting sustainable productivity of maize crops, particularly under irrigated moisture regimes. The study highlights the importance of judiciously applying chemical and organic nutrients in an integrated manner. By doing so, proper nutrient supply to the maize crop is ensured, leading to sustained crop productivity and improved soil quality in maize-based cropping systems. This integrated nutrient management approach proves to be a viable option for farmers aiming to achieve long-term sustainability and productivity in maize cultivation. Overall, adopting a balanced and integrated nutrient management strategy that combines chemical fertilizers with organic sources like Neem cake and biofertilizers is crucial for enhancing crop productivity, preserving soil fertility, and maintaining the overall health of the soil in maize-based cropping systems.

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