

Reclaiming Barren Coal Mine Land into Productive Farmland through Organic Manures and Bio-fertilizers: Effects on Growth and Yield of High Value Crops

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Abstract

Coal mine soils are generally characterized by poor physical structure, low organic carbon content, and deficiencies of essential plant nutrients, which limit crop growth and productivity. The present field experiment was conducted during December 2025–March 2026 at the Gare Palma Coal Mine area of M/s. Hindalco Industries Ltd., Baljore, Tamnar Tehsil, Raigarh District, Chhattisgarh State, India, to evaluate the effects of organic manures, chemical fertilizer, and bio-fertilizers on the growth, yield, and soil properties of Brinjal (*Solanum melongena* L.). The experiment was laid out in a Complete Randomized Design with seven treatments and three replications. The treatments included farmyard manure (FYM), vermicompost, diammonium phosphate (DAP), a consortium of bio-fertilizers [vesicular-arbuscular mycorrhizal (VAM) fungi, *Azospirillum brasilense*, *Bacillus megaterium*, and *Frateuria aurantia*], and their combinations. The results revealed significant differences among treatments for all growth and yield parameters. The combined application of FYM, vermicompost, and bio-fertilizers (T7) recorded the highest plant height (64.10 cm), number of branches (26.39 plant⁻¹), number of leaves (86.72 plant⁻¹), number of flowers (28.64 plant⁻¹), number of fruits (44.50 plant⁻¹), fruit length (19.71 cm), fruit diameter (34.47 mm), fruit weight (362.44 g), and fruit yield (2.99 kg plant⁻¹). In contrast, the control treatment (T1) recorded the lowest values for all growth and yield attributes. Soil analysis conducted before and after the experiment indicated substantial improvements in organic carbon, available nitrogen, phosphorus, potassium, and sulfur contents following treatment application. The integrated use of organic manures and bio-fertilizers was more effective than the application of chemical fertilizer alone in enhancing crop performance and soil fertility. The study demonstrates that the combined application of FYM, Vermicompost, VAM fungi, *Azospirillum brasilense*, *Bacillus megaterium*, and *Frateuria aurantia* is a sustainable and effective nutrient management strategy for improving Brinjal productivity and restoring soil health in coal mine-degraded lands.

Keywords: Bio-fertilizers, Brinjal, Coal mine soil, Bio-manure, VAM fungi.

Introduction

Mining is one of the major industrial sectors in India and plays a significant role in the country's economic development. Along with agriculture and forestry, mining has contributed substantially to the supply of essential raw materials required for human civilization, including metals, minerals, fuels, rocks, and construction materials. Various metallic and non-metallic minerals such as bauxite, coal, iron ore, manganese, copper, gold, and limestone are extensively extracted across different states of India. Among these resources, coal occupies a strategic position as a primary source of energy. The coal mining industry contributes significantly to India's energy security and economic growth by supporting industrial development, power generation, and employment opportunities. India ranks among the leading coal-consuming countries globally, and the demand for coal continues to increase due to rapid industrialization and urbanization. Coal extraction is generally carried out through two principal methods: opencast (surface) mining and underground mining.

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However, opencast mining often results in substantial environmental degradation, including the removal of vegetation, topsoil, and wildlife habitats, leading to alterations in landscape structure and loss of agricultural productivity. Mining activities significantly disturb soil properties, including soil horizons, structure, microbial populations, and nutrient cycling processes that are essential for maintaining ecosystem health (Kundu and Ghose, 1997). The removal and displacement of soil layers during mining operations result in the destruction of native vegetation and deterioration of soil quality. In addition, coal mining contributes to greenhouse gas emissions and economic losses associated with environmental degradation. Overburden (OB) materials generated during mining are typically characterized by unfavorable conditions such as low organic matter content, poor moisture retention, high compaction, elevated sand content, and increased bioavailability of metals. Furthermore, the presence of sulfide-bearing materials in mine spoils can lead to acid mine drainage, posing additional environmental challenges (Ghose, 2005).

The successful reclamation of mined lands depends not only on the establishment of vegetation cover but also on the restoration of soil biological functions, particularly microbial communities. Although extensive research has been conducted worldwide on mine reclamation, the process remains costly and technically challenging (Aznar-Sánchez *et al.*, 2018). Conventional physical and chemical remediation methods are often expensive and less effective, especially in abandoned or large-scale mining areas (Mendez and Maier, 2008; Bolan *et al.*, 2014; Kefeni *et al.*, 2017). Consequently, there is a growing need for cost-effective, environmentally sustainable, and long-term restoration strategies, particularly in developing countries where mining activities occupy extensive areas (Simate and Ndlovu, 2014; Humphries *et al.*, 2017). Soil microorganisms play a crucial role in ecosystem restoration by facilitating nutrient cycling, decomposing organic matter, improving soil structure, and enhancing the availability of essential nutrients required for plant growth (Whitman *et al.*, 1998; Gadd, 2010; Madsen, 2011). Beneficial microorganisms such as plant growth-promoting rhizobacteria (PGPR) and vesicular-arbuscular mycorrhizal (VAM) fungi form symbiotic associations with plant roots and contribute significantly to plant establishment and productivity in degraded environments. Bio-fertilizers containing beneficial microorganisms such as *Azospirillum*, *Azotobacter*, phosphate-solubilizing bacteria (*Bacillus* spp.), potassium-mobilizing bacteria (*Frateuria aurantia*), and VAM fungi have been recognized as effective tools for improving soil fertility and supporting revegetation in mine spoils.

Bio-fertilizers are microbial inoculants that enhance soil fertility and plant growth through various biological processes. They represent an environmentally friendly alternative to chemical fertilizers, which may adversely affect soil health and contribute to environmental pollution (Vives-Peris *et al.*, 2020). The application of bio-fertilizers in degraded ecosystems, particularly mine spoils, has shown considerable potential for improving soil quality, increasing crop productivity, and enhancing biodiversity and ecosystem services (Vives-Peris *et al.*, 2020; Fasusi *et al.*, 2021). Based on the type of microorganisms involved, bio-fertilizers can be broadly classified into four categories: nitrogen-fixing, phosphate-solubilizing, potassium-solubilizing, and plant growth-promoting rhizobacteria (PGPR) (Mahmud *et al.*, 2021). Nitrogen-fixing bio-fertilizers, including *Rhizobium*, *Azotobacter*, and *Azospirillum*, improve the nitrogen status of soils. Phosphate-solubilizing bacteria such as *Bacillus* and *Pseudomonas* increase phosphorus availability by converting insoluble phosphates into plant-accessible forms. Similarly, potassium-solubilizing microorganisms such as *Frateuria aurantia* enhance potassium availability by mobilizing insoluble potassium compounds present in the soil.

In addition to bio-fertilizers, the application of organic manures is essential for improving soil fertility and productivity in reclaimed mine areas. Organic amendments such as farmyard manure (FYM) and vermicompost play a critical role in transforming nutrient-deficient and physically degraded mine spoils into productive soils. Mine overburden materials are generally characterized by low organic carbon content, poor water-holding capacity, high bulk density, and the potential presence of phytotoxic heavy metals. The incorporation of FYM and vermicompost improves soil organic carbon, enhances the availability of nitrogen, phosphorus, and potassium, and supplies essential micronutrients required for plant growth. Furthermore, organic manures improve soil porosity, aeration, and moisture retention, thereby creating favorable conditions for root development. They also help reduce the bioavailability and mobility of toxic heavy metals such as cadmium, lead, and chromium, thereby minimizing their uptake by crops and improving overall soil health.

The increasing cost and environmental concerns associated with chemical fertilizers have prompted the search for sustainable alternatives. Excessive and prolonged use of inorganic fertilizers may adversely affect soil microbial populations, reduce soil fertility, and contribute to environmental pollution. These concerns are particularly relevant for small and marginal farmers, for whom the high cost of chemical fertilizers often limits their practical use. Therefore, integrating organic manures and bio-fertilizers into soil management practices offers a sustainable approach for improving crop production while conserving environmental quality. Vegetables constitute an important component of the human diet, providing essential carbohydrates, proteins, vitamins, minerals, dietary fiber, and other nutrients. India is one of the leading producers of vegetables globally and ranks second after China in total vegetable production. According to the National Horticulture Board (2016), India produces approximately 162.89 million tonnes of vegetables from an area of 9.72 million hectares. Among the various vegetable crops cultivated in India, Brinjal (*Solanum melongena* L.), commonly known as eggplant, is one of the most important and widely grown vegetables. Belonging to the family Solanaceae, Brinjal is valued for its nutritional and medicinal properties and is considered a rich source of vitamins, minerals, and dietary fiber. The crop is also reported to possess cardiogenic, laxative, and analgesic properties.

Considering the importance of sustainable mine land reclamation and crop production in degraded soils, the present study was undertaken to evaluate the effects of organic manures (farmyard manure and vermicompost), chemical fertilizer (diammonium phosphate [DAP]), and bio-fertilizers (VAM fungi, *Azospirillum*, *Bacillus*, and *Frateruria aurantia*) on the growth and yield of Brinjal cultivated in barren coal mine land conditions. The field experiment was conducted at the Gara Palma Coal Mine area of M/s Hindalco Industries Ltd., Baljore, Tamnar Tehsil, Raigarh District, Chhattisgarh State, India. The study aimed to assess the potential of organic manures and bio-fertilizers as sustainable alternatives to chemical fertilizers for improving soil health, enhancing crop productivity, and promoting environmentally sound reclamation of barren coal mine lands.

Materials and Methods

Study Area and Experimental Period: A field experiment was conducted during the winter season (December 2025–March 2026) at the Gara Palma Coal Mine area of M/s Hindalco Industries Ltd., Baljore, Tamnar Tehsil, Raigarh District, Chhattisgarh, India. The study aimed to evaluate the effects of organic manures, chemical fertilizer, and bio-fertilizers on the growth and yield performance of Brinjal (*Solanum melongena* L.) cultivated under barren coal mine soil conditions.

Plant Species Selected for the Study: Brinjal (*Solanum melongena* L.), commonly known as eggplant, belonging to the family Solanaceae, was selected for the present investigation. Brinjal is one of the most widely cultivated vegetable crops in India and many other tropical and subtropical regions of the world. The crop is valued for its nutritional and medicinal properties and is commonly consumed across different socio-economic groups. Owing to its adaptability, economic importance, and suitability for cultivation under diverse environmental conditions, Brinjal was selected as the test crop for the present study.

Seed Source: Healthy and certified seeds of Brinjal were procured from Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu, India.

Seed Pre-treatment: Brinjal seeds generally do not require pretreatment for germination. However, to enhance germination rate and uniformity, seeds were soaked in water for 12–24 h prior to sowing. The soaked seeds were subsequently shade-dried for approximately 30 min and sown in nursery beds established within the Gara Palma Coal Mine area.

Potting Medium: The potting medium used for raising seedlings consisted of solar-sterilized sand, soil, and farmyard manure (FYM) mixed in a ratio of 1:2:1 (v/v/v). The medium was analyzed for its physico-chemical characteristics, including pH, electrical conductivity (EC), available nitrogen (N), available phosphorus (P), available potassium (K), and micronutrients following standard analytical procedures. Available nitrogen and phosphorus were estimated according to Jackson (1973), available potassium following Sankaram (1966), and

micronutrients following Lindsay and Norvell (1978). Data on physico-chemical properties of the potting medium used for raising Brinjal seedlings is given in Table 1.

Table 1. Physico-chemical properties of the potting medium used for raising Brinjal seedlings.

Property	Value
Texture	Sandy loam
pH	7.5 (slightly alkaline)
EC (dS m ⁻¹)	0.09 (very low salinity)
Organic carbon (%)	0.25 (low)
Available N (kg ha ⁻¹)	308 (medium)
Available P (kg ha ⁻¹)	21.5 (low)
Available K (kg ha ⁻¹)	269 (medium)
Cu (ppm)	1.06
Zn (ppm)	1.65
Fe (ppm)	10.20
Mn (ppm)	11.12

Raising of Seedlings: Fresh and healthy Brinjal seeds were sown in nursery beds measuring 10 m × 1 m. The nursery beds were filled with a 5-cm layer of solar-sterilized sand, soil, and FYM mixture (1:2:1). Seeds were sown using the layering method and covered with a thin layer of sterilized fine sandy soil. Watering was carried out twice daily using a sprinkler system. Germination commenced approximately 7 days after sowing, and seedlings were maintained under optimal moisture conditions until transplantation.

Field Experimental Trial: The field trial was conducted in the selected experimental area within the Gara Palma Coal Mine site. Prior to transplantation, the field was thoroughly prepared by ploughing and removing weeds and unwanted vegetation in the selected experimental field site. Pits measuring approximately 15–20 cm³ were dug at a spacing of 2 ft × 2 ft. Field preparation activities were completed during November and December 2025.

Experimental Design: The experiment was laid out in a Complete **Randomized Design (CRD)** comprising seven treatments and three replications. Details of experimental design and treatment details are given in Tables 2a and 2b.

Table 2a. Experimental Design.

Particulars	Description
Crop tested	Brinjal (<i>Solanum melongena</i> L.)
Experimental design	Complete Randomized Design (CRD)
Number of treatments	7
Number of replications	3
Plants per treatment per replication	130
Total plants in experiment	2,730
Spacing	2 ft × 2 ft

Table 2b: Treatment Details.

Treatment	Description
T1	Control
T2	Farmyard manure (FYM) alone
T3	Vermicompost alone
T4	Recommended dose of chemical fertilizer (DAP) alone
T5	Biofertilizers (VAM + <i>Azospirillum brasilense</i> + <i>Bacillus megaterium</i> + <i>Fratureia aurantia</i>)
T6	FYM + Vermicompost + Recommended dose of DAP
T7	FYM + Vermicompost + Biofertilizers (VAM + <i>Azospirillum brasilense</i> + <i>Bacillus megaterium</i> + <i>Fratureia aurantia</i>)

Soil Analysis: Soil samples were collected from the experimental field before the initiation of the experiment (S-1) and after the completion of the experiment (S-2). The samples were analyzed for texture, pH, EC, organic carbon, available N, P, and K, and selected secondary nutrients following standard laboratory procedures.

Table 3. Physicochemical Properties of Soil Samples Collected Before and After the Field Experiment.

Soil Property	S-1 (Before Experiment)	S-2 (After Experiment)
Texture	Sandy clay loam	Sandy clay loam
pH	7.642	7.101
Electrical conductivity (dS m ⁻¹)	0.215	0.282
Organic carbon (%)	0.211	0.957
Available nitrogen (kg ha ⁻¹)	91.05	498.72
Available phosphorus (kg ha ⁻¹)	11.58	33.92
Available potassium (kg ha ⁻¹)	110.71	412.36
Sulphur (mg kg ⁻¹)	9.76	15.57
Calcium (meq 100 g ⁻¹)	12.63	5.76
Magnesium (meq 100 g ⁻¹)	15.81	4.32

Note: S-1 = Soil sample collected before initiation of the field experiment; S-2 = Soil sample collected after completion of the field experiment. EC = Electrical conductivity. Values are based on laboratory analysis of soil samples collected from the experimental field at the Gara Palma Coal Mine area, Raigarh district, Chhattisgarh state, India.

Transplantation of Seedlings: Uniform and healthy 30-day-old Brinjal seedlings were transplanted into the experimental plots during December 2025. Seedlings were planted according to the treatment combinations described in Tables 2a and 2b, with each treatment replicated three times.

Growth and Yield Measurements: Survival percentage was recorded one month after transplantation (January 2026). Growth and yield observations were recorded at 90 days after transplantation (March 2026). The following parameters were measured:

Plant Height (cm): Plant height was measured from the soil surface to the apical growing point using a measuring scale and expressed in centimeters (cm).

Number of Branches per Plant: The total number of primary branches per plant was counted and expressed as the number of branches per plant.

Number of Leaves per Plant: The total number of leaves present on each plant was counted and expressed as leaves per plant.

Number of Flowers per Plant: The total number of flowers produced per plant was recorded and expressed as flowers per plant.

Number of Fruits per Plant: The total number of fruits harvested from each plant was counted and expressed as fruits per plant.

Fruit Length (cm): Fruit length was measured using a measuring scale and expressed in centimeters (cm).

Fruit Diameter (cm): Fruit diameter was measured at the widest portion of the fruit and expressed in centimeters (cm).

Fruit Weight (g): The weight of individual fruits was measured using an electronic weighing balance and expressed in grams (g).

Fruit Yield per Plant (kg): Total fruit yield per plant was determined by weighing all harvested fruits from an individual plant and expressed in kilograms (kg).

Statistical Analysis: The experiment was conducted using a Complete Randomized Design with three replications. Data recorded for growth and yield parameters were subjected to analysis of variance (ANOVA) to determine the significance of treatment effects. When significant treatment effects were observed, means were separated using Duncan's Multiple Range Test (DMRT) at the 5% significance level ($p < .05$). All statistical analyses were performed using SPSS PC+ Studentware (Version 1990; SPSS Inc., Chicago, IL, USA).

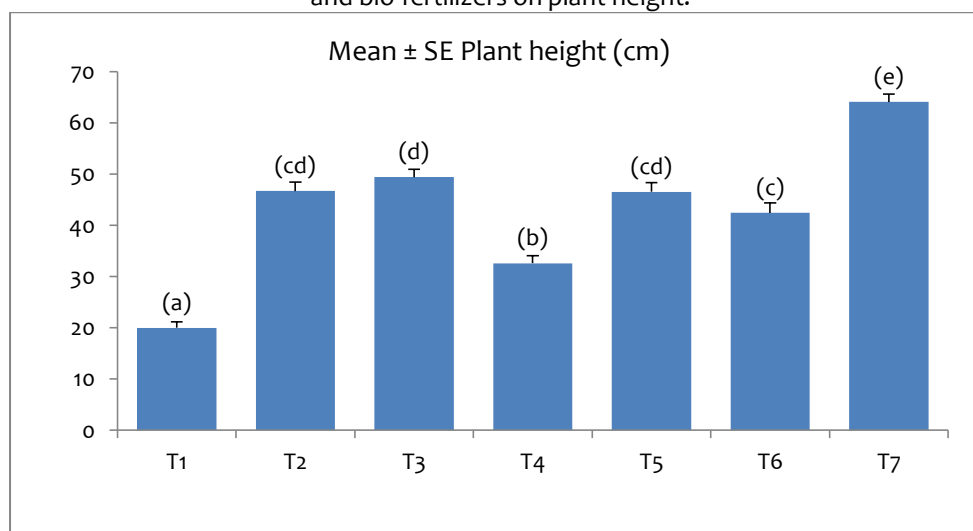
Results and Discussion

The field experiment was conducted from November 2025 to March 2026 at the Gare Palma Coal Mine, Baljore, Tamnar Tehsil, Raigarh District, Chhattisgarh State, India. The effects of organic manures, chemical fertilizer, and bio-fertilizers on growth, yield, and soil properties of Brinjal (*Solanum melongena* L.) grown in coal mine soil were evaluated. The results are presented and discussed in relation to findings reported in previous studies.

Effects of nutrient management treatments on growth parameters

Plant height: Plant height differed significantly among treatments (Fig. 1). The highest mean plant height was recorded in Treatment T7 (FYM + vermicompost + VAM + *Azospirillum brasilense* + *Bacillus megaterium* + *Fratureia aurantia*), with a mean value of 64.10 cm. This value was significantly greater than those observed in all other treatments. Vermicompost alone (T3) resulted in a plant height of 49.42 cm, followed by FYM alone (T2; 46.72 cm) and the biofertilizer consortium (T5; 46.56 cm). Moderate plant height was observed in T6 (42.42 cm), whereas the lowest values occurred in the control (T1; 20.03 cm) and chemical fertilizer alone (T4; 32.58 cm). The enhanced plant growth under T7 may be attributed to the synergistic effects of organic manures and beneficial microorganisms, which improve soil structure, nutrient availability, root development, and nutrient uptake efficiency.

Figure 1: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on plant height.

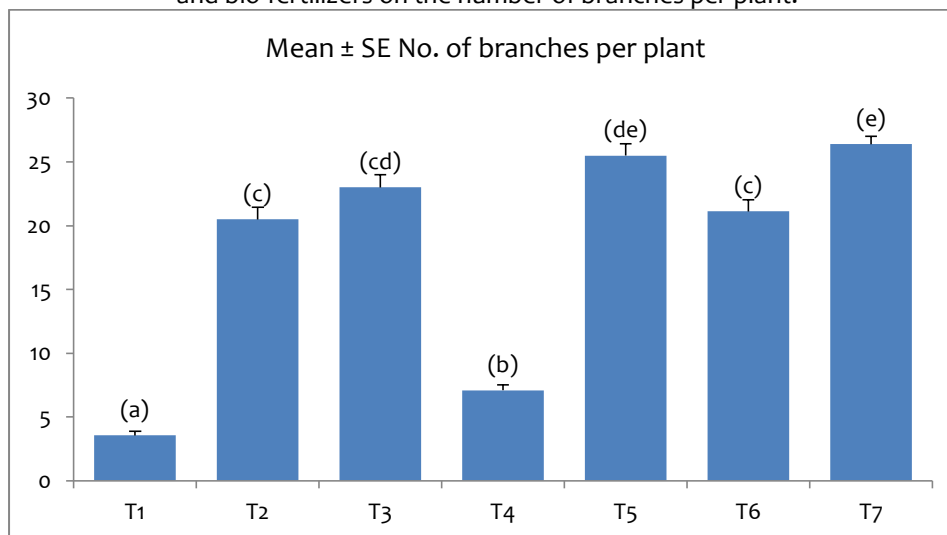


(Note: Bars represent mean plant height $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different).

Number of branches per plant: The number of branches per plant was significantly influenced by nutrient management treatments (Fig. 2). The highest number of branches was recorded under T7 (26.39), followed by T5 (25.50), with both treatments statistically comparable. Vermicompost alone (T3) produced 23.00 branches per plant, while T6 resulted in 21.11 branches. The lowest values were observed in the control (3.56) and chemical fertilizer alone (7.08).

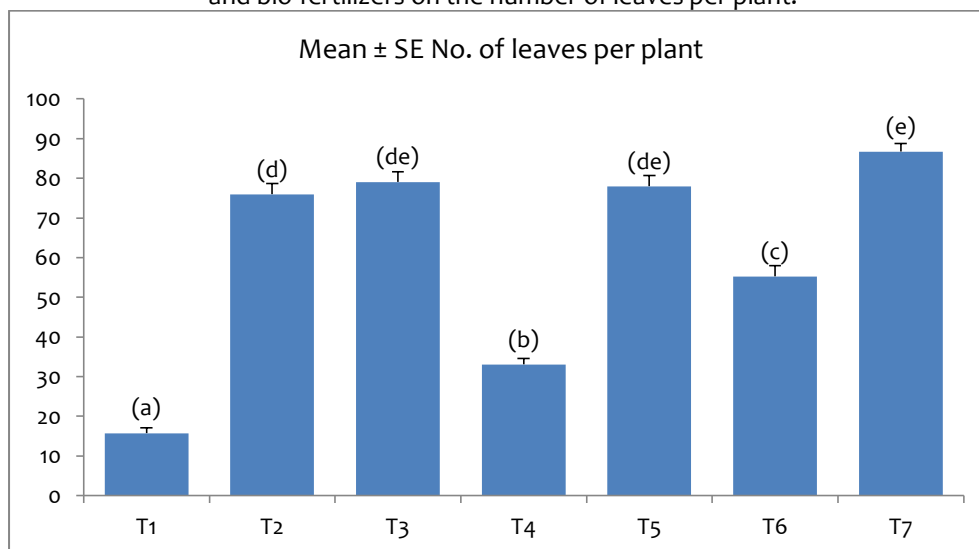
Number of leaves per plant: Significant treatment effects were observed for the number of leaves per plant (Fig. 3). Treatment T7 produced the highest number of leaves (86.72), followed by T3 (79.06), T5 (77.94), and T2 (75.94). Treatment T6 resulted in 55.22 leaves per plant, whereas the control (15.72) and T4 (33.06) recorded the lowest values. The superior vegetative performance of T7 indicates that integrated nutrient management involving organic manures and bio-fertilizers promotes photosynthetic activity and enhances nutrient assimilation, thereby stimulating leaf production and canopy development.

Figure 2: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on the number of branches per plant.



(Note: Bars represent mean number of branches per plant $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different).

Figure 3: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on the number of leaves per plant.



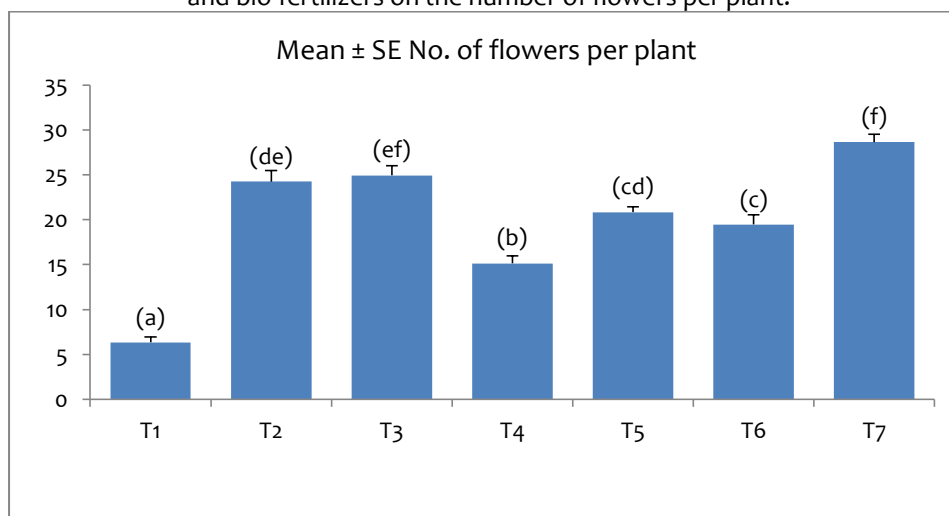
(Note: Bars represent mean number of leaves per plant $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different).

Discussion of growth parameters: Overall, T7 consistently produced the greatest improvements in plant height, branching, and leaf production. The combination of FYM, vermicompost, and bio-fertilizers likely enhanced nutrient cycling, microbial activity, and soil physical properties, resulting in improved plant growth. Similar findings have been reported by Jose *et al.* (1988), Rahman *et al.* (1998), Anburani and Manivanna (2002), Suge *et al.* (2011), Altaf *et al.* (2019), Ujjwal *et al.* (2022) and Paswet and Sharma (2023), who demonstrated that integrated nutrient management improves vegetative growth in vegetable crops.

Effects of nutrient management treatments on yield parameters

Number of flowers per plant: Treatment effects on flower production were significant (Fig. 4). The highest number of flowers per plant was obtained under T7 (28.64), followed by T3 (24.94) and T2 (24.25). The lowest flower production occurred in the control (6.33), whereas T4 produced 15.14 flowers per plant.

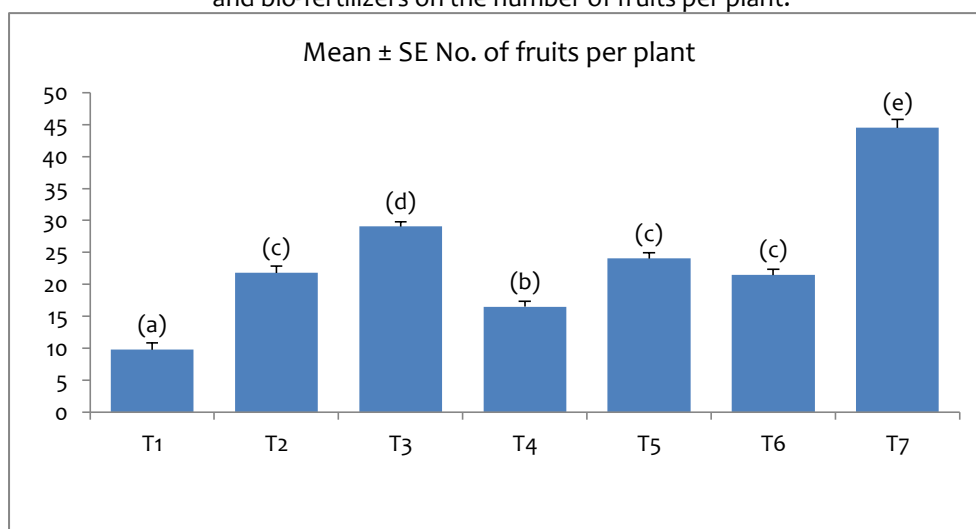
Figure 4: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on the number of flowers per plant.



(Note: Bars represent mean number of flowers per plant $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different).

Number of fruits per plant: Fruit production varied significantly among treatments (Figure 5). Treatment T7 produced the highest number of fruits per plant (44.50), followed by T3 (29.06), T5 (24.00), T2 (21.78), and T6 (21.47). The control recorded the lowest fruit number (9.75).

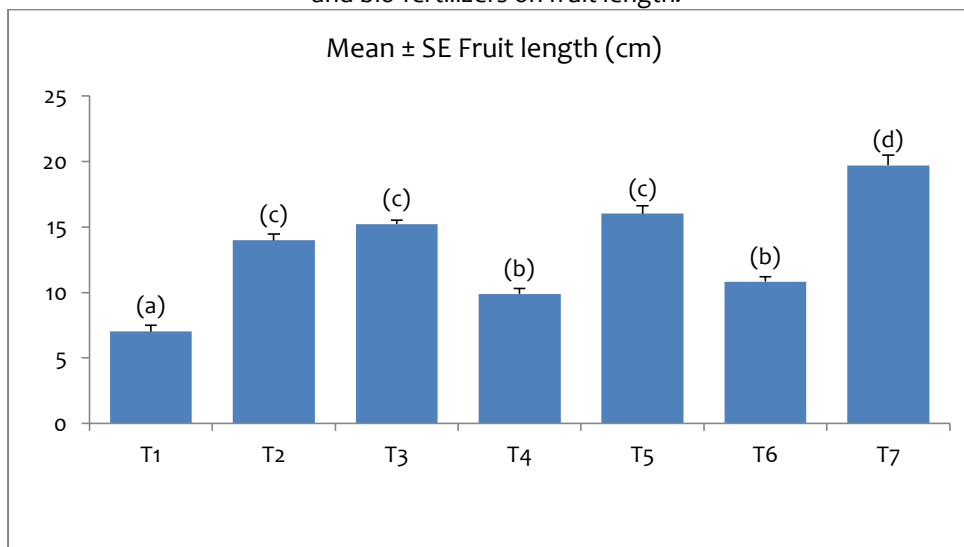
Figure 5: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on the number of fruits per plant.



(Note: Bars represent mean number of fruits per plant $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different).

Fruit length: The longest fruits were obtained under T7 (19.71 cm), followed by T5 (16.03 cm), T3 (15.22 cm), and T2 (13.90 cm) (Fig. 6). The shortest fruits were observed in the control treatment (7.03 cm).

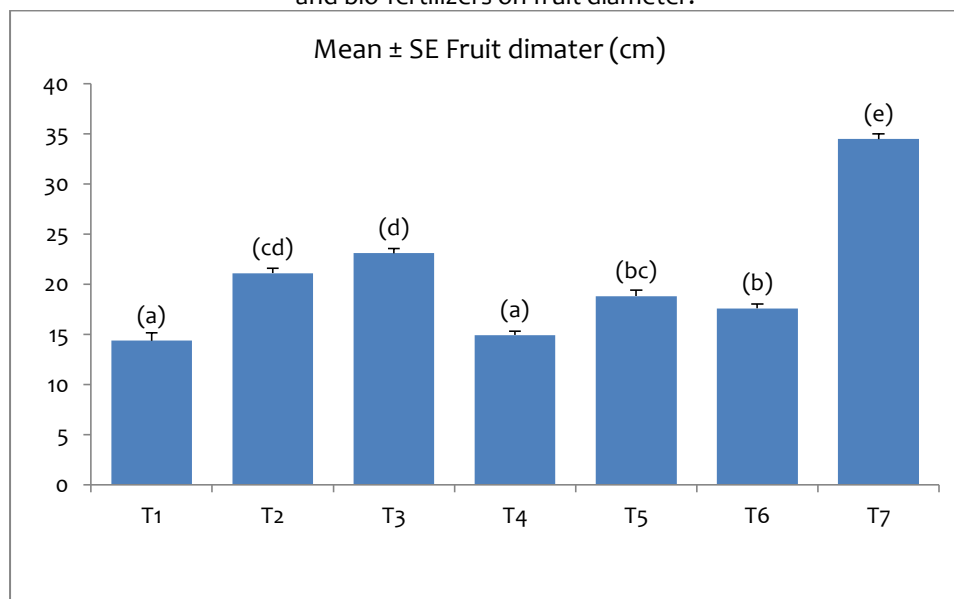
Figure 6: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on fruit length.



(Note: Bars represent mean fruit length $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different).

Fruit diameter: Fruit diameter was highest under T7 (34.47 mm), followed by T3 (23.08 mm) and T2 (21.07 mm) (Fig. 7). The control and T4 recorded the lowest fruit diameters.

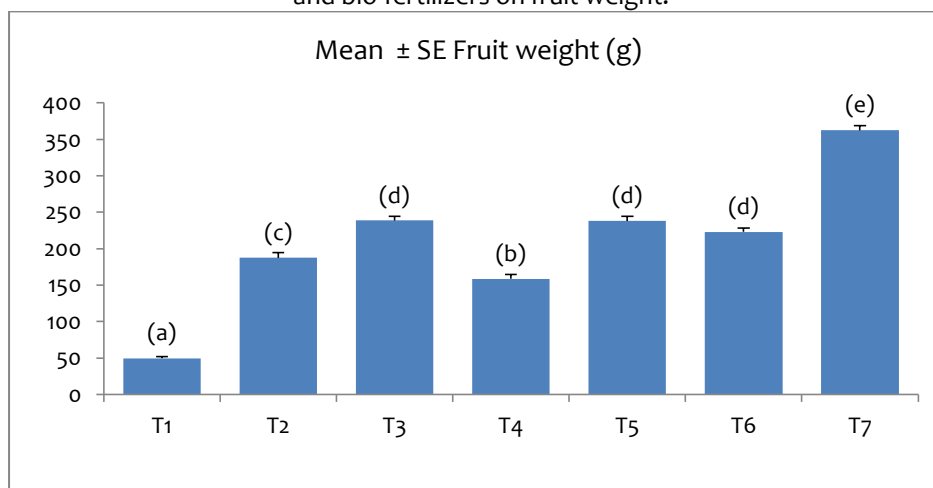
Figure 7: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on fruit diameter.



(Note: Bars represent mean fruit diameter $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different)

Fruit weight: Treatment T7 produced the highest fruit weight (362.44 g per fruit), followed by T3 (238.56 g), T5 (238.00 g), and T6 (222.92 g) (Fig. 8). The control recorded the lowest fruit weight (49.42 g).

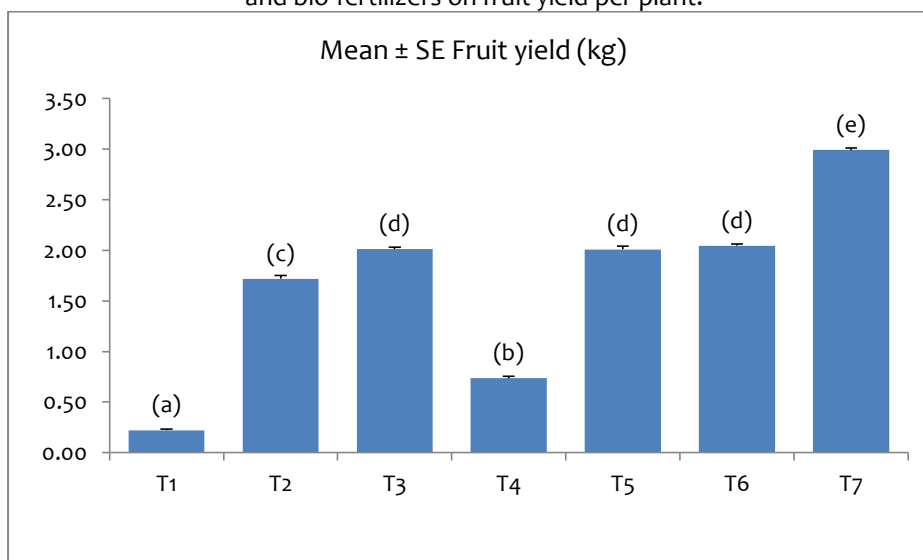
Figure 8: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on fruit weight.



(Note: Bars represent mean fruit weight $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different).

Fruit yield: Fruit yield was significantly influenced by nutrient management treatments (Fig. 9). Treatment T7 recorded the highest yield (2.99 kg plant⁻¹), followed by T6 (2.05 kg plant⁻¹), T3 and T5 (2.01 kg plant⁻¹ each), and T2 (1.72 kg plant⁻¹). The lowest yields were observed in the control (0.22 kg plant⁻¹) and T4 (0.74 kg plant⁻¹).

Figure 9: Effect of different treatment combinations of organic manures, chemical fertilizer and bio-fertilizers on fruit yield per plant.



(Note: Bars represent mean fruit weight $\pm$ SE. Different lowercase letters above the bars indicate significant differences among treatments as determined by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, whereas treatments sharing the same letter are not significantly different).

Discussion of yield parameters: The superior performance of T7 across all yield attributes demonstrates the effectiveness of combining organic manures with bio-fertilizers for improving reproductive growth and productivity in coal mine soils. Improved nutrient availability, enhanced microbial activity, and better root growth likely contributed to increased flowering, fruit set, fruit size, and overall yield. These findings are consistent with previous reports by Jablonska (1990), Hosmani (1993), Devi et al. (2002a, 2002b), Choudhury et al. (2005), Ullah et al. (2008), Kiran et al. (2010), Mishra et al. (2018), Gargi and Dubey (2020), and Ujjwal et al. (2022).

Effects of nutrient management treatments on soil properties: Changes in soil physicochemical properties before and after the experiment are presented in Table 3. Prior to treatment application, the soil was characterized by alkaline pH, low organic carbon content, and low concentrations of available nitrogen, phosphorus, and potassium. Following the experiment, soil pH decreased to a slightly alkaline range, while organic carbon and available macronutrients increased substantially. Concentrations of sulphur, calcium, and magnesium also improved and remained within optimal ranges. The improvement in soil quality may be attributed to the addition of organic manures and bio-fertilizers, which enhance organic matter content, nutrient mineralization, microbial activity, and nutrient retention. Similar improvements in soil fertility following organic amendments have been reported by Wells et al. (2000), Yadav et al. (2002), and Ullah et al. (2008).

Conclusion

The results demonstrated that Treatment T7, consisting of FYM, vermicompost, VAM, *Azospirillum brasilense*, *Bacillus megaterium*, and *Frateruria aurantia*, was the most effective nutrient management strategy for improving growth, yield, and soil fertility in Brinjal cultivated on coal mine soil. This treatment significantly enhanced plant height, branching, leaf production, flowering, fruit development, fruit weight, and fruit yield compared with the control and chemical fertilizer alone. The findings indicate that integrated application of organic manures and bio-fertilizers can effectively improve soil quality and crop productivity in degraded mine soils and may serve as a sustainable strategy for ecological restoration and agricultural utilization of coal mine-affected lands.

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