

Optimizing Soil Nutrients in Pearl Millet through Combined Use of Inorganic Fertilizers and Bio-Amendments

ABSTRACT:

A two-year field experiment was conducted during the Kharif seasons of 2023 and 2024 to assess the impact of inorganic fertilizers combined with Jeevamrutha and Beejamrutha on soil physico-chemical properties and nutrient availability. The study, laid out in a Randomized Block Design comprised with 11 treatments and three replications. Soil bulk density, particle density, porosity, water holding capacity, pH, electrical conductivity, organic carbon, and available nitrogen, phosphorus, and potassium were evaluated at 0-15 and 15-30 cm soil depths after harvest. Results indicated that T₁₁ (100% RDF + Beejamrutha + Jeevamrutha) consistently exhibited the highest available nitrogen (296.71 and 298.69 kg ha⁻¹) and potassium (288.10 and 258.35 kg ha⁻¹), while T₂ (100% RDF) and T₉ (100% RDF + Beejamrutha) were superior for surface and sub-surface phosphorus, respectively. T₈ (50% RDF + Beejamrutha + Jeevamrutha) enhanced soil organic carbon (0.71% and 0.62%), porosity (48.60% and 48.74%), and maintained low bulk density (1.27 and 1.28 Mg m⁻³), contributing to improved soil structure and aeration, whereas water holding capacity was highest in T₁₀ at the surface and T₈ at the sub-surface. Control plots (T₁) consistently showed the lowest nutrient levels, organic carbon, and water retention, alongside higher bulk density. Overall, integrating organic amendments with inorganic fertilizers significantly improved nutrient availability and soil physical properties, with T₁₁ emerging as the most effective treatment for sustaining soil fertility and structure, demonstrating the potential of integrated nutrient management for sustainable agriculture.

KEYWORDS:

Integrated Nutrient Management, Jeevamrutha, Beejamrutha, Inorganic Fertilizers, Soil Fertility and Pearl Millet

INTRODUCTION:

Sustainable agriculture aims to meet present food needs while conserving the environment for future generations, with soil health being a core pillar (FAO, 2015). Modern industrialized farming-characterized by excessive chemical inputs, monocropping, and soil mismanagement has led to erosion, nutrient depletion, and biodiversity loss. Globally, over one-third of soils are degraded (Lal, 2020), threatening food production and climate resilience. Healthy soils provide nutrient cycling, water storage, and carbon sequestration; increasing soil organic carbon by 0.4% annually could offset 1.2 billion tons of CO₂ (Lal, 2019). Among sustainable practices, Jeevamrutha and Beejamrutha-biofertilizers rich in beneficial microbes (Palekar, 2006)-enhance nutrient availability, suppress pathogens, and improve soil biological activity. Beejamrutha, in particular, aids seed germination and

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disease control (Patel *et al.*, 2020). Integrated Nutrient Management (INM), combining these with inorganic fertilizers, boosts productivity, organic carbon, and microbial abundance (Sharma *et al.*, 2020).

Pearl millet (*Pennisetum glaucum*) is a climate-resilient cereal valued for its nutrition, drought tolerance, and economic importance, especially in arid regions (FAO, 2018; Yadav *et al.*, 2019). Rich in iron and zinc (Rai *et al.*, 2019), it also supports food security and livestock feed systems.

Inorganic fertilizers have driven yield gains since the Green Revolution but their overuse has caused soil acidification, nutrient imbalance (FAI, 2023), nitrate leaching, and reduced microbial diversity (Gupta *et al.*, 2022). India imports a major share of its phosphates and potash (DAC&FW, 2023), with subsidies exceeding ₹2.25 lakh crore. Balancing their benefits with ecological safety requires integrating organic inputs like Jeevamrutha and Beejamrutha to sustain soil health and yields while reducing environmental harm.

MATERIALS AND METHODS:

SITE OF STUDY: The experiment was carried out at the Central Research Farm of the Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology, and Sciences, located in Prayagraj district (25°40' N, 81°85' E; 92 m above sea level). The site is situated on the eastern bank of the Yamuna River near Indalpur village, falling within the Middle and Upper Gangetic Plains agro-climatic zones. The area experiences a humid subtropical climate characterized by hot summers (often exceeding 40°C), cool to mild winters (4-25°C), and an average annual rainfall of about 981 mm, primarily concentrated between July and September. Fertile alluvial soils, along with irrigation from rivers and canals, support the cultivation of a wide variety of crops, including cereals, pulses, oilseeds, and vegetables.

LAYOUT AND TREATMENT DETAILS: The field experiments were conducted during the Kharif seasons of 2023 and 2024, following a Randomized Block Design (RBD) comprising 11 treatments and 3 replications. The treatment structure included: T₁ - Absolute control, T₂ - 100% RDF, T₃ - 0% RDF + Beejamrutha, T₄ - 0% RDF + Jeevamrutha, T₅ - 0% RDF + Beejamrutha + Jeevamrutha, T₆ - 50% RDF + Beejamrutha, T₇ - 50% RDF + Jeevamrutha, T₈ - 50% RDF + Beejamrutha + Jeevamrutha, T₉ - 100% RDF + Beejamrutha, T₁₀ - 100% RDF + Jeevamrutha, and T₁₁ - 100% RDF + Beejamrutha + Jeevamrutha. Each plot measured 2 m × 2 m, resulting in a total of 33 plots with a net cultivated area of 132 m², while the overall experimental area covered 25.6 m². The crop was sown at a spacing of 45 cm between rows and 15 cm between plants, using a seed rate of 5 kg ha⁻¹. The Recommended Dose of Fertilizers (RDF) applied was 70:35:35 kg N:P:K ha⁻¹.

METHODS OF SOIL ANALYSIS FOR DIFFERENT PARAMETERS: The physical properties of the soil were analyzed following standard procedures. Bulk density, particle density, porosity, and water

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holding capacity were determined using the methods outlined by Muthuval *et al.* (1992). The chemical parameters included soil pH and electrical conductivity, measured as per Jackson (1973). Organic matter content was estimated using the Walkley and Black (1934) method, available nitrogen was determined by the alkaline permanganate method of Subbaiah and Asija (1956), available phosphorus by the Olsen *et al.* (1954) method, and available potassium by the flame photometric method described by Toth and Prince, (1949).

RESULTS AND DISCUSSION

Soil Bulk Density (Mg m^{-3})

In 2023, at 0-15 cm depth, the highest bulk density (1.32 Mg m^{-3}) was recorded in T₄, while the lowest (1.28 Mg m^{-3}) was observed in T₂, T₆, T₇, and T₈. At 15-30 cm depth, the highest bulk density (1.31 Mg m^{-3}) occurred in T₁, T₃, and T₅, whereas the lowest (1.27 Mg m^{-3}) was recorded in T₆ and T₈. In 2024, at 0-15 cm depth, the highest bulk density (1.30 Mg m^{-3}) was found in T₁, T₃, T₄, and T₅, while the lowest (1.26 Mg m^{-3}) was in T₈. At 15-30 cm depth, the highest bulk density (1.33 Mg m^{-3}) was recorded in T₄, and the lowest (1.29 Mg m^{-3}) in T₇. For the pooled data, at 0-15 cm depth, the highest bulk density (1.31 Mg m^{-3}) was in T₄, and the lowest (1.27 Mg m^{-3}) in T₈. At 15-30 cm depth, the highest bulk density (1.32 Mg m^{-3}) was observed in T₄, while the lowest (1.28 Mg m^{-3}) was in T₈. The F-test results indicated that differences among treatments were significant only for 0-15 cm depth in 2024, while for all other cases, differences were non-significant, meaning the observed variations could be due to natural variability rather than treatment effects.

Soil Particle Density (Mg m^{-3})

In 2023, at the 0-15 cm depth, the highest particle density (2.49 Mg m^{-3}) was recorded in treatments T₁, T₃, and T₅, while the lowest (2.46 Mg m^{-3}) was in T₂. At the 15-30 cm depth, the highest value (2.50 Mg m^{-3}) was observed in T₁, T₃, and T₄, whereas the lowest (2.47 Mg m^{-3}) occurred in T₂ and T₁₀. In 2024, at the 0-15 cm depth, the maximum particle density (2.49 Mg m^{-3}) was recorded in T₁, T₃, T₄, T₅, and T₆, while the minimum (2.47 Mg m^{-3}) occurred in T₂, T₁₀, and T₁₁. At the 15-30 cm depth, the highest (2.55 Mg m^{-3}) was found in T₉, and the lowest (2.52 Mg m^{-3}) in T₂, T₆, T₈, and T₁₀. For the pooled data, at 0-15 cm depth, the highest particle density (2.49 Mg m^{-3}) was in T₁, T₃, T₄, and T₅, while the lowest (2.47 Mg m^{-3}) was in T₂, T₈, and T₁₀. At the 15-30 cm depth, the maximum (2.55 Mg m^{-3}) was recorded in T₉, and the minimum (2.50 Mg m^{-3}) in T₂, T₈, and T₁₀. Since the F-test was non-significant (NS) for all comparisons, the differences in particle density among treatments were not statistically reliable, meaning they could be due to natural variation rather than treatment effects.

Porosity (%)

In 2023, at the 0-15 cm depth, the highest porosity (48.34%) was recorded in T₆, while the lowest (46.85%) was observed in T₄. At the 15-30 cm depth, the maximum porosity (49.01%) occurred in T₆, and the minimum (47.30%) in T₁₁. In 2024, at the 0-15 cm depth, the highest porosity (48.99%) was

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recorded in T8, and the lowest (47.72%) in T3 and T4. At the 15-30 cm depth, the maximum value (49.21%) was found in T7, while the minimum (47.30%) was observed in T4. For the pooled data, at 0-15 cm depth, the highest porosity (48.60%) was observed in T8, whereas the lowest (47.28%) was in T4. At the 15-30 cm depth, the maximum porosity (48.74%) occurred in T8, and the minimum (47.66%) in T4. The F-test results indicated non-significant (NS) differences across all treatments, meaning that variations in porosity values were not statistically proven to be due to treatment effects and may have occurred due to natural variation.

Water Holding Capacity (%)

In 2023, at the 0-15 cm depth, the highest water holding capacity (46.10%) was recorded in T10, while the lowest (44.61%) occurred in T3. At the 15-30 cm depth, the maximum (46.64%) was in T8, and the minimum (45.31%) in T1. In 2024, at the 0-15 cm depth, the highest value (48.31%) was recorded in T10, and the lowest (46.10%) in T1. At the 15-30 cm depth, the maximum (48.96%) was observed in T8 and T9, whereas the minimum (47.37%) was in T1. For the pooled data, at the 0-15 cm depth, the highest water holding capacity (47.21%) occurred in T10, and the lowest (45.67%) in T4. At the 15-30 cm depth, the maximum (47.80%) was recorded in T8, while the minimum (46.34%) was in T1. The F-test indicated that differences were non-significant (NS) for all depths and years except at the 0-15 cm pooled data, where the difference was significant (S), meaning that at this depth, treatments had a statistically proven effect on water holding capacity, while in other cases, variations could be due to natural variability rather than treatment effects.

Soil pH

In 2023, at the 0-15 cm depth, the highest soil pH (7.09) was recorded in T1, while the lowest (6.78) occurred in T10. At the 15-30 cm depth, the maximum (7.13) was again observed in T1, and the minimum (7.00) in T11. In 2024, at the 0-15 cm depth, the highest pH (6.99) was recorded in T1, and the lowest (6.65) in T2. At the 15-30 cm depth, the maximum (7.03) occurred in T1, while the minimum (6.87) was in T9. For the pooled data, at the 0-15 cm depth, the highest pH (7.04) was observed in T1, and the lowest (6.72) in T2 and T9. At the 15-30 cm depth, the maximum (7.08) was recorded in T1, and the minimum (6.94) in T9 and T11. The F-test indicated that all differences were non-significant (NS), implying that the variations in soil pH among treatments were not statistically meaningful and could be attributed to natural variability rather than the treatment effects.

Soil Electrical Conductivity (dS m^{-1})

In 2023, at the 0-15 cm depth, the highest EC (0.36 dS m^{-1}) was recorded in T2 and T6, while the lowest (0.32 dS m^{-1}) occurred in T3 and T11. At the 15-30 cm depth, the maximum EC (0.36 dS m^{-1}) was found in T2 and T6, and the minimum (0.33 dS m^{-1}) in T10 and T11. In 2024, at the 0-15 cm depth, the highest EC (0.38 dS m^{-1}) was recorded in T2, and the lowest (0.34 dS m^{-1}) in T10 and T11. At the 15-30 cm depth, the highest EC (0.35 dS m^{-1}) was observed in T1, T5, T6, T7, and T8, while the lowest (0.31 dS m^{-1}) occurred in T10. For the pooled data, at the 0-15 cm depth, the highest EC (0.37 dS m^{-1}) was in T2, and the lowest (0.33 dS m^{-1})

in T11. At the 15-30 cm depth, the maximum (0.36 dS m^{-1}) was in T6, and the minimum (0.32 dS m^{-1}) in T10. The F-test values were non-significant (NS) across all depths and years, indicating that variations in soil EC among treatments were not statistically significant and likely resulted from natural variability rather than treatment effects.

Soil Organic Carbon (%)

In 2023, at the 0-15 cm depth, the highest SOC (0.70%) was recorded in T8, while the lowest (0.42%) occurred in T1. At the 15-30 cm depth, the maximum SOC (0.62%) was observed in T7, and the minimum (0.38%) in T1. In 2024, at the 0-15 cm depth, the highest SOC (0.72%) was again in T8, with the lowest (0.39%) in T1. At the 15-30 cm depth, the maximum SOC (0.63%) was in T8, and the minimum (0.37%) in T1. For the pooled mean, at the 0-15 cm depth, T8 recorded the highest SOC (0.71%), while T1 had the lowest (0.41%). At the 15-30 cm depth, the maximum SOC (0.62%) was observed in T7 and T8, and the minimum (0.38%) in T1. The F-test indicated significant (S) differences across treatments in all depths and years, suggesting that the application of inorganic fertilizers conjugated with Jeevamrutha and Beejamrutha had a clear positive influence on SOC levels, with combined treatments showing superior performance over control.

Available Nitrogen in Soil (kg ha^{-1})

In 2023, at the 0-15 cm depth, the highest available nitrogen ($294.42 \text{ kg ha}^{-1}$) was recorded in T11, while the lowest ($197.25 \text{ kg ha}^{-1}$) was in T1. At the 15-30 cm depth, the maximum ($291.06 \text{ kg ha}^{-1}$) was also in T11, and the minimum ($190.37 \text{ kg ha}^{-1}$) in T1. In 2024, at the 0-15 cm depth, the highest available nitrogen ($299.00 \text{ kg ha}^{-1}$) was again recorded in T11, and the lowest ($182.10 \text{ kg ha}^{-1}$) in T1. At the 15-30 cm depth, the maximum ($306.32 \text{ kg ha}^{-1}$) was observed in T11, while the minimum ($174.37 \text{ kg ha}^{-1}$) was in T1. For the pooled mean, at the 0-15 cm depth, the maximum available nitrogen ($296.71 \text{ kg ha}^{-1}$) was in T11, and the minimum ($189.67 \text{ kg ha}^{-1}$) in T1. At the 15-30 cm depth, the highest ($298.69 \text{ kg ha}^{-1}$) was again in T11, while the lowest ($182.37 \text{ kg ha}^{-1}$) was in T1. The F-test indicated significant (S) differences across all years and depths, confirming that inorganic fertilizers conjugated with Jeevamrutha and Beejamrutha significantly enhanced soil nitrogen availability compared to the control.

Available Phosphorous in Soil (kg ha^{-1})

In 2023, at the 0-15 cm depth, the highest available phosphorus (18.81 kg ha^{-1}) was recorded in T2, while the lowest (10.31 kg ha^{-1}) occurred in T1. At the 15-30 cm depth, the maximum (16.50 kg ha^{-1}) was in T5, whereas the minimum (10.30 kg ha^{-1}) was observed in T8. In 2024, at the 0-15 cm depth, the highest available phosphorus (21.28 kg ha^{-1}) was in T11, with the lowest (10.37 kg ha^{-1}) in T1. At the 15-30 cm depth, the maximum (19.25 kg ha^{-1}) was also in T11, while the minimum (8.91 kg ha^{-1}) occurred in T1. For the pooled mean, at the 0-15 cm depth, the highest available phosphorus (19.85 kg ha^{-1}) was recorded in T2, followed closely by T11 (19.36 kg ha^{-1}), and the lowest (10.34 kg ha^{-1}) in T1. At the 15-30 cm depth, the maximum (17.54 kg ha^{-1}) was observed in T9, while the lowest (10.62 kg ha^{-1}) was in T1. The F-test revealed significant (S) differences across all years and depths, indicating that the integration of inorganic fertilizers with

Jeevamrutha and Beejamrutha substantially improved available phosphorus levels in the soil compared to the control.

Available Potassium in Soil (kg ha⁻¹)

In 2023, at the 0-15 cm soil depth, the highest available potassium (287.12 kg ha⁻¹) was recorded in T11, followed closely by T10 (286.77 kg ha⁻¹) and T9 (286.54 kg ha⁻¹), while the lowest (205.74 kg ha⁻¹) occurred in T1. At the 15-30 cm depth, the maximum (257.82 kg ha⁻¹) was also observed in T11, with the minimum (174.47 kg ha⁻¹) in T1. In 2024, at the 0-15 cm depth, the highest available potassium (289.09 kg ha⁻¹) was again in T11, and the lowest (188.87 kg ha⁻¹) in T1. At the 15-30 cm depth, the highest (258.88 kg ha⁻¹) was in T11, and the lowest (163.92 kg ha⁻¹) was in T1. For the pooled mean over both years, at the 0-15 cm depth, the highest potassium content (288.10 kg ha⁻¹) was found in T11, while the lowest (197.30 kg ha⁻¹) was in T1. At the 15-30 cm depth, T11 also maintained the highest value (258.35 kg ha⁻¹), and T1 the lowest (169.20 kg ha⁻¹). The F-test showed significant differences (S) across all years and depths, confirming that the integration of inorganic fertilizers with Jeevamrutha and Beejamrutha-particularly in T11-markedly improved soil potassium availability compared to the control.

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CONCLUSION

The two-year study demonstrated that integrating inorganic fertilizers with Jeevamrutha and Beejamrutha significantly improved soil fertility and structure. T₁₁ (100% RDF + Beejamrutha + Jeevamrutha) proved most effective, recording the highest available nitrogen and potassium, while T₂ and T₉ excelled in surface and sub-surface phosphorus, respectively. Organic amendments, particularly in T₈, enhanced soil organic carbon, porosity, and reduced bulk density, indicating better aeration and water retention. Control plots showed the poorest soil health, emphasizing the necessity of integrated nutrient management for sustainable productivity.

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Table.1 Effect of Inorganic Fertilizers and Bio-Amendments on Physical parameter of soil as pooled value

| Treatments | Bulk Density (Mg m ⁻³) | | Particle Density (Mg m ⁻³) | | Porosity (%) | | Water Holding Capacity (%) | |
|------------|------------------------------------|-------|--|-------|--------------|-------|----------------------------|-------|
| | 0-15 | 15-30 | 0-15 | 15-30 | 0-15 | 15-30 | 0-15 | 15-30 |
| T1 | 1.30 | 1.31 | 2.49 | 2.52 | 47.86 | 47.91 | 45.88 | 46.34 |
| T2 | 1.28 | 1.30 | 2.47 | 2.50 | 48.12 | 47.95 | 46.66 | 47.26 |
| T3 | 1.30 | 1.31 | 2.49 | 2.52 | 47.53 | 47.89 | 45.68 | 46.36 |
| T4 | 1.31 | 1.32 | 2.49 | 2.52 | 47.28 | 47.66 | 45.67 | 46.60 |
| T5 | 1.30 | 1.31 | 2.49 | 2.52 | 47.83 | 47.92 | 46.07 | 46.72 |
| T6 | 1.28 | 1.29 | 2.48 | 2.51 | 48.57 | 48.61 | 46.08 | 46.94 |
| T7 | 1.28 | 1.29 | 2.48 | 2.52 | 48.49 | 48.73 | 46.26 | 47.38 |
| T8 | 1.27 | 1.28 | 2.47 | 2.50 | 48.60 | 48.74 | 46.23 | 47.80 |
| T9 | 1.29 | 1.31 | 2.48 | 2.51 | 47.73 | 47.98 | 47.01 | 47.79 |
| T10 | 1.29 | 1.30 | 2.47 | 2.50 | 47.86 | 47.74 | 47.21 | 46.99 |
| T11 | 1.29 | 1.31 | 2.48 | 2.51 | 47.82 | 47.76 | 47.11 | 47.27 |
| F-Test | NS | NS | NS | NS | NS | NS | S | NS |

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Table:2 Effect of Inorganic Fertilizers and Bio-Amendments on Chemical parameter of soil as pooled value

| Treatments | Soil pH | | Soil EC (dS m ⁻¹) | | SOC (%) | |
|------------|---------|-------|-------------------------------|-------|---------|-------|
| | 0-15 | 15-30 | 0-15 | 15-30 | 0-15 | 15-30 |
| T1 | 7.04 | 7.08 | 0.34 | 0.35 | 0.41 | 0.38 |
| T2 | 6.72 | 6.99 | 0.37 | 0.35 | 0.52 | 0.48 |
| T3 | 6.97 | 7.04 | 0.34 | 0.34 | 0.60 | 0.53 |
| T4 | 6.92 | 7.01 | 0.36 | 0.34 | 0.62 | 0.54 |
| T5 | 6.84 | 6.99 | 0.34 | 0.34 | 0.63 | 0.56 |
| T6 | 6.97 | 7.00 | 0.36 | 0.36 | 0.69 | 0.61 |
| T7 | 6.76 | 6.99 | 0.34 | 0.35 | 0.70 | 0.62 |

