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# Impact of Long Term Organic Nutrient Management on Soil Health and Yield of Little Millet (*Panicum sumatrense*)

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## Abstract

**Aim:** To evaluate the long-term effects of complete organic nutrient management in comparison with conventional inorganic fertilization on soil health, yield, nutrient uptake, and economic returns of little millet (*Panicum sumatrense*).

**Study Design:** A long-term field experiment comparing two nutrient management practices: Complete organic nutrient management and Conventional management with recommended inorganic fertilizers (20–20–20 kg NPK $ha^{-1}$). The study involved pooled analysis of eight consecutive years of data and t test was conducted to test the significance.

**Place and Duration of Study:** The experiment was conducted at the Acharya N.G. Ranga Agricultural University, Agricultural Research Station, Vizianagaram, Andhra Pradesh, India. The study was carried out for eight consecutive *Kharif* seasons from 2015 to 2022.

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**Methodology:** The experimental soil was sandy loam, neutral in reaction, low in organic carbon (0.43%) and available nitrogen (240 kg $ha^{-1}$), and medium in available phosphorus (59 kg $ha^{-1}$) and potassium (315 kg $ha^{-1}$). Two nutrient management treatments were evaluated: Organic management: In situ incorporation of green manure (sunhemp), application of farmyard manure (FYM), neem cake, and biofertilizers (Azospirillum and phosphorus-solubilising bacteria). Conventional management: Application of recommended dose of inorganic fertilizers (20–20–20 kg NPK $ha^{-1}$). Soil health parameters, grain yield, nutrient availability, and benefit–cost (B:C) ratio were recorded and analyzed annually. Pooled data were subjected to statistical analysis.

**Results:** Pooled analysis of eight years of experimentation revealed that the yield advantage of organic nutrient management became evident after six years of continuous application. In the sixth year, organic management recorded a grain yield of 833 kg $ha^{-1}$, which was 9.46% higher than the yield obtained under conventional fertilization (761 kg $ha^{-1}$), with corresponding benefit–cost (B:C) ratios of 1.34 and 1.81, respectively. In the seventh year, the superiority of organic management became more pronounced, producing a significantly higher grain yield of 941 kg $ha^{-1}$, representing an 11.2% increase over inorganic fertilization (846 kg $ha^{-1}$); the B:C ratios were 1.62 under organic and 2.35 under inorganic management. During the eighth year, organic plots registered a further significant increase in grain yield (1017 kg $ha^{-1}$), showing a 12.2% advantage over inorganic plots (906 kg $ha^{-1}$), with B:C ratios of 2.39 and 2.60, respectively. In addition to yield improvement, soil health parameters showed marked enhancement under organic management, with significant increases in available nitrogen, phosphorus, zinc, iron, and manganese compared to inorganic fertilization. Soil organic carbon content in organic plots increased from 0.43% to 0.51%, although the improvement was not statistically significant over the conventional treatment. Overall, the results indicate a progressive yield advantage and improvement in soil fertility under sustained organic nutrient management.

**Conclusions:** The long-term study demonstrates that sustained organic nutrient management enhances soil fertility, micronutrient availability, and grain yield of little millet over time. Although conventional fertilization showed relatively higher B:C ratios in earlier years, organic management progressively improved productivity and economic returns. The findings indicate that complete organic nutrient management is a viable and sustainable strategy for maintaining long-term productivity and environmental health in little millet cultivation.

*Keywords: Little millet; organic farming; conventional farming; soil health; yield.*

## 1. Introduction

Sustainable nutrient management is a central pillar for achieving long-term productivity and soil health in agricultural systems. The increasing global demand for food production, coupled with concerns over environmental degradation and soil fertility decline, has renewed interest in organic agriculture and alternative nutrient management practices. Soil health encompassing physical, chemical and biological attributes is now widely acknowledged as a key driver of crop productivity and ecosystem sustainability (Xu et al., 2025). Millets, including little millet (*Panicum sumatrense*), are climate-resilient cereals with nutritional advantages and adaptability to marginal environments. They play an important role in the sustainability of rainfed agroecosystems and in enhancing food and nutritional security in semi-arid regions (Mukherjee et al., 2025). Despite their potential, yield constraints often arise from low soil fertility and suboptimal nutrient inputs, particularly under traditional management systems.

Involving organic manures, green manures, biofertilizers and crop residues has been repeatedly shown to improve soil structure, increase organic carbon and enhance nutrient cycling, compared to exclusive reliance on inorganic fertilizers. Organic practices also tend to increase microbial activity and biodiversity in the soil, which cumulatively improve soil health over time (Vijaykumar & Patnaik, 2025). In contrast, continuous use of inorganic fertilizers can lead to depletion of soil organic matter, micronutrient imbalances and reduced resiliency of soil ecosystems. This degradation is increasingly highlighted in soil health assessments, including Indian soils that are low in organic carbon and nutrient availability (CSE, 2025).

Several recent field studies demonstrate the benefits of organic and integrated nutrient strategies. Long-term incorporation of farmyard manure (FYM) improved soil organic carbon and nutrient availability in cereal systems, showing that organic amendments can sustain soil fertility and crop yields across seasons (Sheoran et al., 2025). Similarly, integrated nutrient management combining organic inputs with inorganic fertilizers enhanced pearl millet yield and soil properties, underscoring the value of balanced nutrient strategies for both productivity and soil health (Yadav et al., 2024). Comparative studies also suggest that, while exclusively organic management may have lower yields in the short term for some crops, its advantages in soil quality and nutrient cycling increase over time. Indeed, strategic combinations of organic and inorganic inputs can bridge yield gaps and improve economic viability. Furthermore, meta-analyses and systematic reviews highlight that organic practices can significantly enhance soil organic matter, nutrient retention, and microbial functioning, key indicators of long-term sustainability (Vijaykumar & Patnaik, 2025).

In millet systems, research specific to long-term organic versus conventional nutrient management is limited, especially under rainfed conditions where nutrient constraints and climate risks are pronounced. Literature on millet nutrient management emphasizes that balanced organic and inorganic nutrient inputs improve soil fertility and crop performance more effectively than either source alone (Warisa et al., 2025). However, systematic long-term comparisons remain scarce for little millet (*Panicum sumatrense*), despite its potential for climate-smart and sustainable cultivation. Given this background, the current long-term field experiment was designed to evaluate the impact of complete organic nutrient management relative to conventional fertilization on soil health, yield and nutrient uptake in little millet. The findings aim to contribute robust evidence on the sustainability and agronomic performance of organic systems in a millet-based rainfed environment.

## 2. Material and Methods

The field experiment was conducted for a period of eight years from *kharif* 2015 to 2022 at Agricultural Research Station, Vizianagaram, ANGRAU, to study the effect of organic farming using only organic inputs in comparision with conventional method of farming using inorganic fertilizers on growth parmeters, yield, soil fertility status and nutrient uptake at harvest in little millet. The soil was sandy loam in texture, neutral in reaction with low soluble salts, low in organic carbon and available nitrogen, while, high in available phosphorus and potassium. The experiment was laid out with two treatments i.e. organic treated plot and inorganic treated plot (conventional plot). The recommended dose of fertilizer (20:20:20 kg NPK ha$^{-1}$) was applied to inorganic treated plot and green manure, FYM@ 5t ha$^{-1}$ along with 0.50 t ha$^{-1}$ of Neem cake was applied as top dressing to organic treated plot. Recommended dose of nitrogen, phosphorus and potassium were applied through single super phosphate and muriate of potash as basal dose. Moreover green manure (sunhemp) was grown *insitu*, incorporated and biofertilizers in the form of *Azospirillum* and *PSB* @ 5 kg ha$^{-1}$ were applied in organic plot. Before incorporation the biomass of the green manure crop incorporated was quantified and the total nutrients supplied to the organic plot in the form of green maures, FYM and neem cake was also analyzed through standard procedures (Table 1). The crop was harvested at maturity stage and growth characters like plant height, no. of productive tillers/plant, inflorescence length, No. of spikes/panicle and yield attributes like grain yield, straw yield were recorded. Plant samples were collected at harvesting stage to determine nutrient content and nutrient uptake. The final soil samples were collected after harvest of the crop and the available macro and micronutrients were determined by adopting standard procedures. Electrical conductivity (EC) of the soil was measured using a conductivity meter, while soil pH was determined with a pH meter. Available nitrogen was estimated using the Kelplus system following the Subbiah and Asija (1956) method. Soil available phosphorus was determined using a spectrophotometer and available potassium was measured with a flame photometer. Micronutrient concentrations, including zinc ($Zn^{2+}$), manganese ($Mn^{2+}$), copper ($Cu^{2+}$), and iron ($Fe^{2+}$), were analyzed using atomic absorption spectroscopy (AAS).

**Table 1. Nutrient composition of different sources added to the organic and inorganic treatments of little millet**

| Organic source | Fresh biomass accumulation (t ha$^{-1}$) | Dry matter (t ha$^{-1}$) | Nutrient concentration(%) | | | Nutrient accumulation (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| Sunhemp | 13.40 | 1.59 | 1.80 | 0.34 | 1.20 | 27.00 | 5.10 | 18.00 |
| **Organic source** | **Quantity applied (t ha$^{-1}$)** | **Nutrient concentration (%)** | | | **Nutrient accumulation (kg ha$^{-1}$)** | | | |
| | | **N** | **$P_2O_5$** | **$K_2O$** | **N** | **$P_2O_5$** | **$K_2O$** | |
| FYM | 5 | 0.35 | 0.25 | 0.40 | 15.00 | 12.50 | 20.00 | |
| Neem cake | 0.5 | 3.50 | 0.50 | 0.40 | 17.50 | 2.50 | 2.00 | |
| Total Nutrients supplied to organic plot (kg/ha) | | | | | 60 | 20 | 40 | |
| Total Nutrients supplied to inorganic plot (kg/ha) | | | | | 20 | 20 | 20 | |

## 3. Results and Discussion

### 3.1 Yield and Yield Attributing Characters

The pooled analysis of eight years (2015–2022) clearly demonstrated that nutrient management practices exerted a pronounced influence on growth, yield attributes and productivity of little millet. The data over eight consecutive *Kharif* seasons reveals a distinct temporal trend in the productivity of Little Millet. While organic systems often face yield penalties in the initial years of transition, this study demonstrates the long-term dividend of sustained organic management. During the initial five years of experimentation, the inorganic (conventional) treatment recorded significantly higher grain and straw yields compared to organic management, indicating the transitional yield penalty commonly associated with complete organic systems. Grain yield under inorganic fertilization ranged from 670 to 747 kg $ha^{-1}$, whereas organic plots recorded relatively lower yields (501–713 kg $ha^{-1}$) during this phase (Table 3). Similar short-term yield reductions under organic management have been widely reported and are primarily attributed to slower nutrient mineralization, limited immediately available nitrogen and gradual establishment of soil biological activity (Maitra et al., 2022; Knapp and van der Heijden, 2018).

From the sixth year onwards, a clear reversal in yield trends was observed, highlighting the long-term benefits of sustained organic nutrient management. Organic management surpassed inorganic fertilization by 9.46% in the sixth year (833 vs 761 kg $ha^{-1}$), 11.2% in the seventh year (941 vs 846 kg $ha^{-1}$) and 12.2% in the eighth year (1017 vs 906 kg $ha^{-1}$). This progressive yield advantage under organic management reflects the cumulative improvement in soil fertility, nutrient synchronization and biological activity achieved through continuous application of green manure, farmyard manure, neem cake and biofertilizers. Recent long-term studies and reviews have similarly reported that organic systems, although yield-constrained during the conversion phase, gradually close the yield gap and often outperform conventional systems under rainfed and low-input environments due to improved nutrient cycling and enhanced soil resilience (Reganold and Wachter, 2016; Seufert, et al., 2012).

The superior grain yield under organic management during the eighth year was supported by significant improvements in yield attributing characters, including plant height (171.28 cm), number of productive tillers (13.08 $m^{-2}$), boot leaf length, width and inflorescence length compared to inorganic fertilization (Table 2). These improvements indicate enhanced vegetative vigor and assimilate partitioning under organic management. Improved root growth and sustained nutrient availability under organically managed soils are known to enhance photosynthetic efficiency and translocation of assimilates to reproductive sinks, thereby improving grain yield (Yadav et al., 2024).

**Table 2. Effect of organic manures and inorganic fertilizers on yield and yield attributingparameters in Little millet after 8 years**

| Particulars | Organic treatment | Inorganic treatment | T Value | P Value |
|---|---|---|---|---|
| Plant height (cm) | 171.28 | 146.35 | 2.7452** | 0.00789** |
| No. of productive tillers/ $m^2$ | 13.08 | 10.91 | 3.691** | 0.0012** |
| Boot leaf length (cm) | 36.47 | 31.99 | 3.939** | 0.0007** |
| Boot leaf width (cm) | 1.01 | 0.85 | 5.220** | 0.00016** |
| Inflorescence length (cm) | 46.15 | 37.91 | 5.775** | 0.00018** |
| Straw yield (kg/ha) | 6600 | 6343 | 1.299 | 0.107 |
| Grain yield (kg/ha) | 1017 | 906 | 4.033** | 0.00062** |
| Gross Returns (Rs/ha) | 34275 | 31440 | | |
| Cost of Cultivation (Rs/ha) | 12600 | 10356 | | |
| Net Returns (Rs/ha) | 21675 | 21084 | | |
| B:C ratio | 2.39 | 2.60 | | |

** Significant at 0.05; ** Significant at 0.01*

**Table 3. Year-wise grain yield and benefit–cost ratio of little millet (var. OLM 203) under organic and inorganic management**

| Treatments | Grain yield (kg/ha) | | | | | | | | Benefit: Cost Ratio | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2015-16** | **2016-17** | **2017-18** | **2018-19** | **2019-20** | **2020-21** | **2021-22** | **2022-23** | **2015-16** | **2016-17** | **2017-18** | **2018-19** | **2019-20** | **2020-21** | **2021-22** | **2022-23** |
| Organic | 501 | 659 | 698 | 707 | 713 | 833 | 941 | 1017 | 0.57 | 0.75 | 0.93 | 0.9 | 1.35 | 1.34 | 1.62 | 2.39 |
| Inorganic | 670 | 858 | 835 | 778 | 747 | 761 | 846 | 906 | 1.28 | 1.64 | 1.6 | 1.73 | 2.31 | 1.81 | 2.35 | 2.60 |

**Table 4. Effect of organic manures and inorganic fertilizers on post-harvest soil parametersafter 8 years in Little millet crop**

| **Particulars** | **Initial values** | **Organic treatment** | **Inorganic treatment** | **T Value** | **P Value** |
|---|---|---|---|---|---|
| pH (1:2.5) | 6.96 | 6.98 | 7.07 | 1.886 | 0.088 |
| EC (dS $m^{-1}$) | 0.24 | 0.26 | 0.31 | 2.070 | 0.017 |
| OC (%) | 0.43 | 0.51 | 0.44 | 0.76 | 0.615 |
| Av. N (kg $ha^{-1}$) | 240 | 254 | 235 | 2.25* | 0.041* |
| Av. $P_2O_5$ (kg $ha^{-1}$) | 59 | 64 | 61 | 2.97* | 0.001* |
| Av. $K_2O$ (kg $ha^{-1}$) | 315 | 326 | 318 | 0.695 | 0.498 |
| Soil Zn (ppm) | 1.22 | 1.85 | 1.39 | 5.32** | 0.00013** |
| Soil Fe (ppm) | 9.60 | 9.32 | 8.35 | 2.90* | 0.0116* |
| Soil Mn (ppm) | 6.03 | 8.40 | 7.19 | 5.23** | 0.00014** |
| Soil Cu (ppm) | 2.35 | 2.19 | 1.98 | 1.64 | 0.122 |

**Table 5. Changes in physico-chemical and chemical properties of soils in Little millet**

| | Organic | | | | | | | | Inorganic | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Soil parameters** | **2015**-16 | **2016**-17 | **2017**-18 | **2018**-19 | **2019**-20 | **2020**-21 | **2021**-22 | **2022**-23 | **2015**-16 | **2016**-17 | **2017**-18 | **2018**-19 | **2019**-20 | **2020**-21 | **2021**-22 | **2022**-23 |
| pH | 6.95 | 7.04 | 7.2 | 6.92 | 7.04 | 7.0 | 6.90 | 6.98 | 6.9 | 7.02 | 7.1 | 6.88 | 7.19 | 7.1 | 7.1 | 7.07 |
| EC ($dSm^{-1}$) | 0.38 | 0.35 | 0.15 | 0.23 | 0.27 | 0.23 | 0.26 | 0.26 | 0.39 | 0.39 | 0.13 | 0.22 | 0.30 | 0.25 | 0.29 | 0.31 |
| O.C. (%) | 0.44 | 0.44 | 0.45 | 0.46 | 0.46 | 0.48 | 0.51 | 0.51 | 0.42 | 0.42 | 0.43 | 0.43 | 0.43 | 0.44 | 0.44 | 0.44 |
| Av.N (kg/ha) | 201 | 222 | 235 | 242 | 237 | 243 | 256 | 254 | 189 | 205 | 226 | 234 | 224 | 235 | 238 | 235 |
| Av. $P_2O_5$ kg/ha) | 61 | 67 | 60 | 64 | 65 | 68 | 66 | 64 | 57 | 61 | 64 | 62 | 61 | 65 | 62 | 61 |
| Av. $K_2O$ (kg/ha) | 316 | 340 | 321 | 326 | 324 | 323 | 322 | 326 | 314 | 314 | 315 | 319 | 299 | 308 | 315 | 318 |
| Av.Zn (ppm) | 1.06 | 1.18 | 1.22 | 0.91 | 1.16 | 1.87 | 1.94 | 1.85 | 0.82 | 0.89 | 1.15 | 0.83 | 0.98 | 1.39 | 1.37 | 1.39 |
| Av. Fe (ppm) | 10.25 | 12.75 | 10.5 | 12.1 | 9.51 | 10.29 | 10.06 | 9.32 | 9.32 | 10.13 | 9.85 | 11.8 | 8.29 | 9.28 | 9.17 | 8.35 |
| Av.Mn (ppm) | 7.32 | 8.77 | 5.43 | 6.43 | 6.14 | 8.54 | 8.84 | 8.40 | 7.48 | 6.70 | 4.35 | 2.35 | 5.71 | 6.37 | 7.04 | 7.19 |
| Av.Cu (ppm) | 3.05 | 3.36 | 2.55 | 2.1 | 2.24 | 2.14 | 2.23 | 2.19 | 2.39 | 2.65 | 2.42 | 1.93 | 2.07 | 1.95 | 2.07 | 1.98 |

### 3.2 Soil Organic Carbon and Physico-Chemical Properties

Soil organic carbon (SOC), a critical indicator of soil health, showed a steady improvement under organic management. The SOC content increased from an initial value of 0.43% to 0.51% after eight years, compared to only 0.44% under inorganic fertilization (Table 4). Although the increase was statistically non-significant, the numerical improvement is agronomically meaningful, particularly in sandy loam soils where organic matter plays a vital role in enhancing aggregation, water-holding capacity and cation exchange capacity.

The year-wise trend (Table 5) clearly indicates a gradual buildup of SOC under organic plots, confirming the cumulative effect of FYM, green manure biomass (1.59 t $ha^{-1}$ dry matter) and neem cake addition. Similar long-term increases in SOC under organic nutrient management have been documented by Vijaykumar and Patnaik (2025) and Ye et al. (2025), who emphasized that organic amendments improve soil carbon stabilization and microbial-mediated carbon sequestration. Soil pH remained near neutral under both treatments, indicating no adverse acidification or alkalization effects. Electrical conductivity (EC) values were marginally higher under inorganic fertilization but remained well within safe limits, confirming that organic inputs did not contribute to salinity buildup.

### 3.3 Soil Available Macronutrients

Significant improvements in available nitrogen and phosphorus were recorded under organic management compared to inorganic fertilization (Table 4). Available nitrogen increased to 254 kg $ha^{-1}$ under organic treatment, compared to 235 kg $ha^{-1}$ under inorganic fertilization. This increase is primarily attributed to biological nitrogen fixation by Azospirillum and mineralization of nitrogen-rich organic inputs such as sunhemp biomass and neem cake.

Available phosphorus ($P_2O_5$) was significantly higher under organic management (64 kg $ha^{-1}$) than inorganic fertilization (61 kg $ha^{-1}$). The organic acids released during decomposition of FYM and green manure, coupled with PSB activity, likely enhanced solubilization of native soil phosphorus. These findings align with recent studies indicating improved phosphorus availability under organic and integrated nutrient management systems due to enhanced microbial activity and chelation processes (Sheoran et al., 2025). Available potassium did not differ significantly between treatments, indicating adequate baseline K status in the soil and balanced nutrient supply under both systems.

### 3.4 Soil Available Micronutrients

One of the most notable outcomes of this long-term experiment was the substantial improvement in soil micronutrient availability under organic management. Soil zinc, iron and manganese levels were significantly higher in organic plots compared to inorganic plots (Table 4). Zinc content increased to 1.85 ppm under organic treatment compared to 1.39 ppm under inorganic fertilization, while iron and manganese also showed significant enhancement.

Organic manures and neem cake act as complete nutrient sources supplying both macro- and micronutrients. Additionally, organic matter functions as a natural chelating agent, preventing micronutrient fixation and maintaining them in plant-available forms. In contrast, continuous application of high-analysis inorganic fertilizers without micronutrient replenishment often leads to micronutrient mining and hidden hunger in soils. Similar observations have been reported by Vijaykumar and Patnaik (2025) and CSE (2025), highlighting the superiority of organic systems in sustaining soil micronutrient balance.

### 3.5 Economics of Organic Vs Inorganic Management

Economic analysis revealed that inorganic fertilization recorded higher B:C ratios during the initial years due to lower input costs and immediate yield response. However, organic management exhibited a consistent improvement in economic returns over time. The B:C ratio increased from 0.57 in the first year to 2.39 by the eighth year under organic management, whereas inorganic plots recorded a B:C ratio of 2.60 during the same year (Table 3). Despite higher cost of cultivation under organic management due to bulky organic inputs and labor requirements, increasing yields and improved soil fertility enhanced system profitability over time. If premium pricing for organically produced millets were considered, organic management would likely surpass conventional systems in net profitability. Similar economic transitions in long-term organic systems have been reported by Yadav et al. (2024).

## 4. Conclusion

The eight-year long-term field experiment conducted at Vizianagaram clearly demonstrates that organic nutrient management is a robust and sustainable approach for the cultivation of little millet (*Panicum sumatrense*). Although organic management involved an initial transition phase with lower yields, continued application of organic inputs resulted in progressive yield improvement, ultimately surpassing conventional fertilization. Sustained organic practices enhanced soil health through improvements in soil fertility, nutrient availability and micronutrient status, contributing to stable and higher productivity over time. The gradual improvement in benefit–cost ratio further indicates a positive economic transition as the system matured. Overall, the findings highlight that long-term organic nutrient management effectively overcomes initial yield constraints and offers a sustainable, climate-resilient strategy for rainfed millet-based production systems.

## Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

## Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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