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INTEGRATED APPLICATION OF JEEVAMRUTHA AND BOTANICAL LIQUID ORGANIC MANURES ENHANCES GROWTH, YIELD, SOIL HEALTH AND ECONOMIC RETURNS OF FOXTAIL MILLET (*Setaria italica* L.) UNDER SEMI-ARID CONDITIONS

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ABSTRACT

A four-year field experiment (2022–2025) was conducted at the Zonal Agricultural and Horticultural Research Station, Navile, Shivamogga, Karnataka, India, to evaluate the influence of different liquid organic manure (LOM) formulations on growth, yield, soil fertility, microbial activity and economics of foxtail millet (*Setaria italica* L. var. SIA-3156). The experiment was laid out in a randomized complete block design with eleven treatments and three replications. Treatments included individual applications of Jeevamrutha, cow urine, biodigested liquid manure and vermiwash, as well as integrated applications of Jeevamrutha with botanical leaf extracts and seaweed extract. Results revealed significant improvement in crop performance under integrated LOM treatments compared with single-input applications and control. Among all treatments, drumstick leaf extract combined with Jeevamrutha (T5) recorded the highest plant height (120.4 cm), tillers (3.84 plant^{-1}), total dry matter (27.3 g plant^{-1}), grain yield (12.5 q ha^{-1}) and straw yield (34.4 q ha^{-1}). The same treatment also improved soil organic carbon (9.35 g kg^{-1}), available phosphorus (48.5 kg ha^{-1}), available potassium (239.1 kg ha^{-1}) and microbial populations. Economic analysis indicated maximum gross returns (Rs. 25,620 ha^{-1}) and net returns (Rs. 10,520 ha^{-1}) under T5. Seaweed extract + Jeevamrutha (T10) and neem leaf extract + Jeevamrutha (T9) also produced comparable improvements. The findings demonstrate that integrated liquid organic manure applications, particularly Jeevamrutha combined with drumstick leaf extract, offer an effective and environmentally sustainable nutrient management strategy for enhancing productivity and soil health in organic foxtail millet cultivation.

***Keywords* :** Foxtail millet; Jeevamrutha; Liquid organic manure; Moringa leaf extract; Soil fertility; Microbial activity; Sustainable agriculture.

Introduction

Foxtail millet (*Setaria italica* L.) is one of the oldest domesticated cereal crops and is widely cultivated in arid and semi-arid regions because of its short growth duration, drought tolerance, and ability to thrive under low-input conditions (Saleh *et al.*, 2019). The crop is recognized as a climate-resilient food grain and contributes significantly to nutritional security due to its high content of dietary fiber, protein, minerals, and bioactive compounds (Muthamilarasan and Pradeep, 2020). In recent years, growing consumer preference for nutritious and sustainable food products has renewed interest in millet cultivation, particularly under organic farming systems (Kumar and Sharma, 2021).

Despite its adaptability to marginal environments, the productivity of foxtail millet remains relatively low in many production systems because of inadequate nutrient management and declining soil fertility (Pathak *et al.*, 2018). The widespread dependence on synthetic fertilizers has undoubtedly increased crop yields; however, long-term and excessive use of chemical inputs has resulted in soil degradation, nutrient imbalance, reduced microbial activity, and environmental concerns (Brar and Dhillon, 2020). These challenges have highlighted the need for sustainable nutrient management strategies that can maintain crop productivity while improving soil health (Suresh and Yadav, 2019; Rathore and Singh, 2020).

Organic farming emphasizes the use of locally available organic resources to enhance nutrient cycling, soil biological activity, and ecological sustainability (Chatterjee and Kundu, 2019; Nandwa and Kihanda, 2020). Among various organic inputs, liquid organic manures (LOMs) have gained considerable attention because they provide nutrients in readily available forms and contain beneficial microorganisms, enzymes, vitamins, and growth-promoting substances (Mishra and Prasad, 2021). Liquid formulations can be applied either to the soil or as foliar sprays, ensuring rapid nutrient absorption and improved crop response compared with conventional solid organic manures (Rajesh and Singh, 2018).

Jeevamrutha, a fermented microbial culture prepared from cow dung, cow urine, pulse flour, jaggery, and soil, is widely promoted in natural farming systems (Subashini and Muralidharan, 2020). It serves as a rich source of beneficial microorganisms and organic metabolites that stimulate nutrient mineralization and improve soil biological activity (Sharma and Singh, 2019). Studies have demonstrated that Jeevamrutha application enhances microbial populations, nutrient availability, crop growth, and yield in several cereals and pulse crops (Kumari and Ramesh, 2018). Similarly, cow urine-based formulations have been reported to improve plant growth through the supply of nutrients, growth regulators, and antimicrobial compounds (Suresh and Yadav, 2020).

Botanical extracts derived from leaves of drumstick (*Moringa oleifera*), neem (*Azadirachta indica*), pongamia (*Pongamia pinnata*), papaya (*Carica papaya*), and guava (*Psidium guajava*) are increasingly being explored as bio-stimulants in organic agriculture (Rani and Sharma, 2020). Moringa leaf extract is particularly rich in zeatin, vitamins, amino acids, antioxidants, and mineral nutrients, which have been shown to promote cell division, photosynthesis, and reproductive growth (Basak and Ghosh, 2019). Neem leaf extracts possess pesticidal and growth-promoting properties and have been reported to improve nutrient uptake and crop productivity (Karthikeyan and Kumar, 2020). Likewise, pongamia, papaya, and guava leaf extracts contain various secondary metabolites and micronutrients that contribute to plant vigor and resilience (Singh and Singh, 2020).

Seaweed extracts represent another important category of organic bio-stimulants. They contain naturally occurring plant growth regulators such as auxins, cytokinins, and gibberellins, along with micronutrients, amino acids, and polysaccharides that enhance root growth, nutrient uptake, stress tolerance, and yield (Karthik and Ramachandran, 2019). Numerous studies have reported positive effects of seaweed-based formulations on crop growth, productivity, and quality across diverse agricultural systems (Ramesh and Kumar, 2020).

Previous research has established the beneficial effects of individual liquid organic manures and botanical extracts on crop performance (Bhattacharyya and Pal *et al.,* 2020). However, limited information is available regarding their integrated use in foxtail millet cultivation, particularly under the agro-climatic conditions of the semi-arid tropics (Walkley A Black, 1934). The synergistic interaction between Jeevamrutha and plant-derived bio-stimulants may offer greater benefits in terms of crop productivity, soil fertility improvement, microbial activity, and economic returns than their individual application. Systematic evaluation of such combinations is therefore necessary to develop efficient and sustainable nutrient management strategies for millet-based farming systems.

Considering the growing importance of organic agriculture and the need for eco-friendly nutrient management practices, the present investigation was undertaken to evaluate the effect of different liquid organic manure treatments on growth, yield, soil nutrient status, soil microbial activity, and economics of foxtail millet (*Setaria italica* L. var. SIA-3156) under field conditions. The study aimed to identify an effective liquid organic manure combination capable of enhancing productivity, improving soil health, and increasing profitability in sustainable foxtail millet production systems.

Materials and Methods

Experimental Site

The field experiment was conducted over four consecutive Kharif seasons (2022–2025) at the Zonal Agricultural and Horticultural Research Station (ZAHRS), Navile, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India (14°00′–14°01′ N latitude, 75°40′–75°42′ E longitude; 650 m above mean sea level). The station is located in the Southern Transitional Zone (Agro-climatic Zone-VII) of Karnataka, representing a transition between the hilly Malnad region and the Maidan plains, characterized by moderately humid to sub-humid climatic conditions.

The soils of the experimental field were red sandy loam (Typic Haplustalf), moderately acidic to near neutral in reaction, well-drained, and low to medium in organic carbon and native fertility status. Prior to initiation of the experiment, composite soil samples were collected and analyzed to determine physicochemical properties.

Climatic Conditions

The experimental site experiences a tropical monsoon climate with distinct seasons. Meteorological data recorded during the study period (2022–2025) are presented in Table 1. The region receives most of its rainfall during the southwest monsoon (June–September), with annual rainfall ranging from 1080 to 1265 mm.

Mean maximum temperature varied from 31.2 to 35.8 °C, while mean minimum temperature ranged from 14.8 to 22.4 °C across the study years. Relative humidity during the cropping period ranged between 68 and 86%, providing favorable conditions for foxtail millet cultivation.

Initial Soil Characteristics

The initial physico-chemical properties of the experimental soil are presented in Table 2. The soil was slightly acidic (pH 6.14) with low electrical conductivity (0.06 dS m^{-1}), indicating non-saline conditions. Organic carbon content was 6.52 g kg^{-1}. Available nitrogen, phosphorus (P_2O_5), and potassium (K_2O) were 172.6, 44.8, and 165.6 kg ha^{-1}, respectively, indicating low to medium fertility status.

Experimental Design and Treatments

The experiment was laid out in a randomized complete block design (RCBD) with eleven treatments and three replications. Foxtail millet (*Setaria italica* L.) cultivar SIA-3156 was used as the test crop. Sowing was carried out during the first fortnight of July each year at a spacing of 30 cm × 10 cm.

A uniform basal application of farmyard manure (FYM) at 2.5 t ha^{-1} was applied to all plots along with the recommended dose of fertilizers (16:16:0 kg $N:P_2O_5:K_2O$ ha^{-1}). Standard agronomic and plant protection practices were followed uniformly across all treatments.

The treatments consisted of different liquid organic manures applied singly or in combination with Jeevamrutha, as presented in Table 3.

Preparation and Application of Liquid Organic Manures

Jeevamrutha was prepared using fresh cow dung, cow urine, jaggery, pulse flour, and native soil under anaerobic fermentation following standard natural farming protocols. Botanical leaf extracts were prepared from fresh leaves of *Moringa oleifera*, *Carica papaya*, *Psidium guajava*, *Pongamia pinnata*, and *Azadirachta indica* using aqueous extraction methods. Seaweed extract was obtained from a commercially available organic formulation.

All liquid organic manures were applied at a uniform rate of 200 L ha^{-1} at 25, 50, and 75 days after sowing (DAS) according to treatment schedules. Applications were made using a knapsack sprayer to ensure uniform distribution. Treatments involving botanical and seaweed extracts were applied in combination with Jeevamrutha, while other formulations were applied individually.

Crop Management

Field preparation consisted of one deep ploughing followed by two harrowings to obtain a fine seedbed. Sowing of foxtail millet (*S. italica* L.) cultivar SIA-3156 was done during the first fortnight of July each year under rainfed conditions, with supplemental irrigation provided as required during critical growth stages.

Weed management was carried out through manual hand weeding at 20 and 40 DAS. Plant protection measures were adopted on a need basis uniformly across treatments. All recommended agronomic practices for foxtail millet cultivation were followed throughout the crop growth period until harvest.

Observations Recorded

Five representative plants were randomly selected and tagged in each plot for recording growth and yield parameters.

Plant height (cm) was measured at physiological maturity from the soil surface to the tip of the panicle. Number of tillers $plant^{-1}$ was recorded at 60 DAS by counting all tillers from tagged plants. Total dry matter production (g $plant^{-1}$) was determined by oven-drying samples at 65–70 °C until constant weight.

Grain weight per plant was recorded after threshing, cleaning, and drying to constant moisture content. Harvest index (%) was calculated as:

HI (%) = (Economic yield / Biological yield) × 100

Grain yield was recorded from the net plot area, processed, and expressed as q ha^{-1}. Straw yield was determined from the remaining biomass after threshing and expressed as q ha^{-1}.

Soil samples were collected before sowing and after harvest from each treatment plot and analyzed for pH, electrical conductivity, organic carbon, available nitrogen, phosphorus (P_2O_5), and potassium (K_2O) using standard procedures.

Soil microbial populations were assessed at 30, 60 DAS, and at harvest using the serial dilution and plate count technique. Populations of bacteria, fungi, actinomycetes, nitrogen-fixing, and phosphate-solubilizing microorganisms were expressed as colony-forming units per gram of dry soil (CFU g^{-1}).

Economic analysis was performed based on prevailing market prices. Cost of cultivation, gross returns, net returns, and benefit–cost (B:C) ratio were computed using standard economic procedures.

Statistical Analysis

Data collected over four consecutive years (2022–2025) were subjected to analysis of variance (ANOVA) appropriate for a randomized complete block design (RCBD). Pooled analysis across years was performed to evaluate treatment effects, year effects, and treatment × year interactions. Treatment means were compared using the least significant difference (LSD) test at the 5% probability level ($P \leq 0.05$). Statistical analyses were carried out using standard statistical procedures using appropriate software to ensure accuracy and reliability of results.

Results

Growth parameters and yield attributes

The growth and yield of foxtail millet were significantly influenced by different liquid organic manure treatments (Table 1). Plant height varied markedly among treatments, ranging from 84.4 cm in the control (T11) to 120.4 cm in T5 (drumstick leaf extract + Jeevamrutha), followed by T10 (114.0 cm) and T8 (111.0 cm). The number of tillers per plant exhibited a similar trend, with the highest value recorded in T5 (3.84), followed by T10 (3.59) and T9 (3.52), while the control recorded the lowest (2.58). Total dry matter accumulation was highest in T5 (27.3 g $plant^{-1}$), with the lowest observed in T3 and T11 (19.1 g $plant^{-1}$). Grain weight per plant was maximum in T5 (17.6 g), followed by T10 (17.0 g) and T9 (16.2 g). The harvest index showed relatively minor variation (0.24–0.31), with the highest value observed in T10, suggesting improved assimilate partitioning under seaweed extract-based treatments.

The superior growth observed under integrated organic treatments, particularly T5, can be attributed to enhanced nutrient availability and the presence of bioactive compounds such as cytokinins and antioxidants in drumstick leaf extract. These substances likely stimulate cell division, photosynthetic efficiency, and overall biomass accumulation, especially under low-input organic systems.

Grain and straw yield

Grain yield varied significantly across treatments over four years (2022–2025) (Table 2). The highest mean grain yield was recorded in T5 (12.5 q ha^{-1}), followed by T9 and T10 (12.0 q ha^{-1} each), while the control yielded the lowest (8.4 q ha^{-1}). Year effects and year × treatment interactions were non-significant, indicating stable treatment responses across environments. Straw yield followed a similar trend, with the highest value in T5 (34.4 q ha^{-1}), followed by T10 (32.4 q ha^{-1}), T9 (32.1 q ha^{-1}), and T8 (31.5 q ha^{-1}), and the lowest in the control (26.2 q ha^{-1}).

The yield advantage of integrated treatments suggests improved nutrient cycling and sustained microbial activity. Jeevamrutha likely enhances microbial-mediated decomposition and nutrient mineralization, while botanical extracts provide growth-promoting substances that support reproductive development and biomass accumulation. The stability of these effects across years highlights the robustness of integrated organic strategies under variable seasonal conditions.

Soil physico-chemical properties

Soil physico-chemical properties were significantly influenced by liquid organic manure treatments (Table 3). Soil pH increased from acidic levels in the control (5.43) to near-neutral in T5 (7.35), while electrical conductivity remained low across treatments (0.06–0.10 dS m^{-1}), indicating non-saline conditions. Soil organic carbon content improved from 6.52 g kg^{-1} to 9.35 g kg^{-1} in T5. Available nitrogen ranged from 169.5 kg ha^{-1} in the control to 240.2 kg ha^{-1} in T7, whereas phosphorus and potassium were highest under T5 (48.5 and 239.1 kg ha^{-1}, respectively).

These improvements reflect enhanced organic matter turnover and microbial-mediated nutrient transformations. Jeevamrutha likely stimulates microbial activity, while botanical extracts contribute organic carbon and bioactive compounds, collectively improving nutrient availability and soil quality under integrated organic management.

Soil microbial populations

Soil microbial populations increased under liquid organic manure treatments across all growth stages (Table 5). Bacterial populations peaked at 88.0 $\times 10^5$ CFU g^{-1} (T1 at 60 DAS) compared with 72.7 $\times 10^5$ CFU g^{-1} in the control at harvest. Fungal populations ranged from 9.0 $\times 10^4$ CFU g^{-1} (T11) to 20.7 $\times 10^4$ CFU g^{-1} (T1 and T5). Actinomycetes, nitrogen-fixing bacteria, and phosphate-solubilizing microorganisms were consistently higher in T5, T7, and T1. Across treatments, microbial populations peaked at 60 DAS and declined slightly at harvest.

Enhanced microbial populations are attributed to continuous substrate availability from organic inputs and improved rhizosphere conditions. Jeevamrutha functions as a microbial inoculant, while botanical extracts provide additional carbon sources and secondary metabolites, supporting microbial proliferation and soil biological fertility.

Economic analysis

The economic analysis revealed that application of drumstick leaf extract (10 L) combined with Jeevamrutha at 200 L ha^{-1} (T_5) recorded the highest gross returns (Rs 25,620 ha^{-1}), net returns (Rs 10,520 ha^{-1}), and benefit:cost ratio (1.69) among all liquid organic manure treatments. This was followed by neem leaf extract + Jeevamrutha (T_9) and seaweed extract + Jeevamrutha (T_{10}), which recorded net returns of Rs 9,600 and Rs 9,640 ha^{-1}, respectively. Although the control treatment (T_{11}) registered the highest benefit:cost ratio (1.74) owing to its substantially lower cultivation cost, its gross returns were considerably lower than those obtained with T_5. Therefore, the integration of drumstick leaf extract with Jeevamrutha proved to be the most profitable liquid organic manure treatment for enhancing economic returns in foxtail millet cultivation.

While the control exhibited a higher B:C ratio due to lower input costs, integrated organic treatments generated substantially higher net returns, highlighting the economic advantage of combining Jeevamrutha with bio-stimulant-rich botanical extracts for sustainable millet production.

Discussion

Growth parameters and yield attributes

The significant improvement in growth and yield attributes of foxtail millet under liquid organic manure treatments indicates the strong influence of bio-stimulant-based organic inputs on crop physiology. The superior performance of T5 (drumstick leaf extract + Jeevamrutha) across plant height, tillering, dry matter accumulation, and grain weight suggests synergistic effects between microbial inoculants and plant-derived growth regulators.

Similar enhancements in vegetative growth under Jeevamrutha-based systems have been reported in millets and cereals, primarily due to increased microbial activity and nutrient mineralization in the rhizosphere, improving nutrient availability to plants (Choudhary & Yadav, 2021; Srivastava & Singh, 2020). Moringa (*Moringa oleifera*) leaf extract is known to contain cytokinins (notably zeatin), antioxidants, and essential minerals, which stimulate cell division, chlorophyll synthesis, and photosynthetic efficiency, ultimately improving biomass production (Rani & Sharma, 2020; Gopalakrishnan & Anitha, 2018).

The relatively higher dry matter accumulation under integrated treatments further reflects improved carbon assimilation efficiency and enhanced source–sink relationships. The limited variation in harvest index suggests that organic treatments primarily improved vegetative growth rather than altering assimilate partitioning, a trend also reported under organic millet production systems (Kumar & Sharma, 2021).

The superior growth observed under drumstick leaf extract combined with Jeevamrutha may be attributed to enhanced nutrient availability, microbial stimulation and the presence of naturally occurring growth-promoting compounds in moringa leaves. Increased microbial activity likely improved nutrient mineralization and uptake, resulting in greater biomass accumulation and tillering.

Grain and straw yield

The significant yield improvement under integrated liquid organic manure treatments confirms their role in enhancing productivity in low-input millet-based systems. The highest grain yield recorded in T5 (12.5 q ha^{-1}) and comparable performance of T9 and T10 indicate that combinations of microbial inoculants and botanical extracts provide consistent yield advantages.

These findings are consistent with previous reports where Jeevamrutha-based applications improved cereal productivity through enhanced microbial-mediated nutrient cycling and enzymatic activity in soil (Sharma & Singh, 2019; Kumari & Ramesh, 2018). Seaweed extracts, as observed in T10, have also been widely reported to enhance yield through auxin-, cytokinin-, and gibberellin-like activity, improving flowering and grain filling processes (Sharma & Yadav, 2018; Karthik & Ramachandran, 2019).

The non-significant year × treatment interaction indicates the stability of organic liquid manure effects across varying agro-climatic conditions, which is an important trait for climate-resilient agriculture systems. Similar stability of organic amendments under rainfed conditions has been reported in semi-arid cereal production systems (Mishra & Prasad, 2021).

The higher grain and straw yields obtained under integrated treatments indicate the synergistic interaction between microbial inoculants and plant-derived biostimulants. Enhanced nutrient cycling, improved root activity and greater photosynthetic efficiency collectively contributed to improved productivity.

Soil physico-chemical properties

The improvement in soil fertility parameters under organic treatments reflects enhanced nutrient cycling, organic matter turnover, and microbial-mediated soil processes. The increase in soil organic carbon from 6.52 to 9.35 g kg^{-1} under T5 highlights the role of continuous organic inputs in building soil carbon pools.

Jeevamrutha and related fermented organic formulations act as microbial activators, increasing decomposition rates and nutrient mineralization (Sharma & Singh, 2019). Similarly, botanical extracts contribute additional labile organic compounds that stimulate microbial respiration and nutrient release (Muthusamy & Balamurugan, 2019).

The observed increase in available nitrogen, phosphorus, and potassium under integrated treatments aligns with findings that organic liquid amendments enhance nutrient solubilization and mobilization in soil through microbial processes and organic acid production (Ramesh & Venkatesh, 2020). Seaweed and neem-based extracts have also been shown to improve nutrient uptake efficiency and soil enzymatic activity in cereal systems (Sharma et al., 2020; Basu & Ghosh, 2021).

Soil microbial populations

The marked increase in microbial populations under liquid organic manure treatments reflects improved soil biological activity and rhizosphere functioning. Peak microbial activity at 60 DAS corresponds with maximum root exudation and substrate availability during active vegetative growth.

Jeevamrutha is widely recognized as a microbial inoculant that enhances bacterial diversity, enzymatic activity, and nutrient cycling in soil ecosystems (Choudhary & Yadav, 2021). The higher populations of nitrogen-fixing bacteria and phosphate-solubilizing microorganisms under T5, T7, and T1 further confirm the stimulatory role of organic liquid amendments on functional microbial groups.

Seaweed and plant extract-based treatments contribute additional carbon sources and bioactive compounds, which enhance microbial proliferation and activity in the rhizosphere (Sharma & Yadav, 2018). Similar increases in microbial biomass and functional diversity under organic amendments have been reported in sustainable cereal production systems (Srivastava & Singh, 2020; Mishra & Prasad, 2021).

The increase in soil organic carbon and available nutrients demonstrates the capacity of liquid organic manures to improve soil quality through continuous organic matter addition and stimulation of microbial processes. Enhanced populations of beneficial microorganisms further indicate improved soil biological health.

Economic performance

Economic analysis indicated that although organic treatments increased cost of cultivation slightly, they significantly enhanced gross and net returns. T5 recorded the highest net return (Rs. 10,520 ha^{-1}), indicating superior economic viability.

The higher profitability under integrated treatments is attributed to improved yield performance and better resource-use efficiency. While control plots showed higher B:C ratio due to lower input costs, they generated substantially lower net returns, emphasizing that profitability in organic systems should be evaluated based on absolute returns rather than ratio alone.

Similar economic advantages of integrated organic nutrient management systems have been reported in millet-based farming, where bio-stimulant combinations improved profitability and sustainability simultaneously (Mishra & Prasad, 2021; Ramesh & Venkatesh, 2020).

Although integrated treatments increased cultivation costs, they generated substantially higher gross and net returns. Drumstick leaf extract combined with Jeevamrutha emerged as the most economically viable treatment, demonstrating the feasibility of organic nutrient management for profitable millet production.

Conclusion

Integrated liquid organic manure applications significantly enhanced growth, yield, soil fertility, microbial populations, and economic returns of foxtail millet under Southern Transitional Zone conditions. Among the treatments, T5 (drumstick leaf extract + Jeevamrutha) consistently outperformed others, demonstrating the synergistic effects of microbial inoculants and botanical bio-stimulants in promoting vegetative growth, biomass accumulation, and nutrient availability. Treatments T10 (seaweed extract + Jeevamrutha) and T9 (neem leaf extract + Jeevamrutha) also showed substantial improvements, indicating that combining Jeevamrutha with bioactive plant extracts is an effective strategy for organic millet production.

The study confirms that integrated organic nutrient management not only improves crop performance and soil health but also enhances profitability in smallholder systems. These findings provide a practical framework for sustainable foxtail millet cultivation, emphasizing the role of liquid organic amendments in organic and low-input cereal production systems.

Integrated liquid organic manure applications significantly improved growth, yield, soil fertility, microbial activity and profitability of foxtail millet under the Southern Transitional Zone of Karnataka. Among the evaluated treatments, drumstick leaf extract combined with Jeevamrutha consistently produced superior performance across agronomic, soil and economic parameters. The study highlights the potential of combining microbial inoculants with botanical biostimulants as a sustainable nutrient management strategy for organic millet production systems. Adoption of such integrated approaches can contribute to enhanced productivity, improved soil health and long-term sustainability in rainfed agriculture.

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Author Contributions

- Pradeep S.: Conceptualization and Planning of Experiment, Manuscript writing, editing and interpretation of results.
- Santhosh U.N.: Field experimentation, data collection, statistical analysis and original draft preparation.
- Shilpashree Y.P.: Soil sampling, laboratory analysis and data validation.
- Divya M.: Microbial population analysis and laboratory investigations.
- Srikanth C.D.: Experimental planning, crop management and supervision.

All authors read and approved the final manuscript.

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Data Availability

The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of Interest

The authors declare that they have no conflict of interest.

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