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Effect of integrated nutrient management on growth, yield and grain quality of foxtail millet (*Setaria italica* L.) under rainfed conditions of Dehradun

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Abstract

Foxtail millet (*Setaria italica* L.) serves as a valuable cereal crop that can withstand challenging climates while providing essential nutrients. Farmers commonly grow this crop in rainfed areas, but yields typically stay low because of poor soil conditions and insufficient nutrient application. Integrated Nutrient Management (INM) presents a promising solution by blending chemical fertilizers with organic materials and biological supplements to boost both crop output and soil quality in an environmentally sustainable way. Researchers carried out this investigation during the 2025-2026 Rabi season at Dev Bhoomi Uttarakhand University's experimental farm in Dehradun. The study aimed to assess how various INM approaches affect the growth, harvest yield, grain characteristics, and financial outcomes of foxtail millet cultivation. Scientists organized the experiment using a Randomized Block Design with ten different treatment combinations. These treatments included varying amounts of the recommended fertilizer dose used alone or mixed with vermicompost, farmyard manure, and Jeevamrut, plus an untreated control group. They cultivated the PRK-1 variety (Pant Setaria-4) under natural rainfall conditions throughout the study period. Findings showed that combining organic and chemical nutrient sources produced notably better results than using fertilizers alone. Plants showed improved growth characteristics, better yield components, higher grain production, and enhanced quality when treated with integrated nutrient systems. The INM approach helped soil retain more moisture and made nutrients more accessible to plants, leading to stronger overall crop performance. Financial calculations demonstrated that treatments using mixed nutrient applications generated greater profit margins and more favourable benefit-cost ratios. This research demonstrates that INM represents a viable approach for achieving sustainable foxtail millet production while increasing farmer profits in rainfed agricultural systems.

Keywords: Foxtail millet, integrated nutrient management, vermicompost, farmyard manure, Jeevamrut, rainfed agriculture, grain quality, yield

1. Introduction

Foxtail millet (*Setaria italica* L.) stands among the world's most ancient cultivated grains, first domesticated approximately 6000 years ago across China and Central Asia. Farmers in dry and semi-dry regions commonly grow this crop because it adapts well to challenging conditions, matures quickly, and withstands both drought and nutrient-poor soils. These qualities make foxtail millet particularly well-suited for farming that depends on rainfall.

This grain has recently attracted increased interest because of its exceptional nutritional benefits. It provides 10-12% protein, 60-65% carbohydrates, valuable dietary fibre, and important minerals including iron, calcium, and phosphorus. The grain's low glycemic index makes it an excellent choice for people managing diabetes and those focused on healthy eating. However, despite these advantages, foxtail millet yields remain disappointing because farmers typically grow it in poor conditions with depleted soils and insufficient nutrient management practices. Integrated Nutrient Management (INM) represents a promising solution that merges chemical fertilizers with organic and biological materials to boost crop production while preserving soil health. Organic materials like farmyard manure, vermicompost, and Jeevamrut improve soil texture, boost beneficial microorganism activity, and increase nutrient accessibility. Meanwhile, chemical fertilizers deliver nutrients that plants can use right away. When farmers use these

approaches together, they see better plant development, higher yields, and improved grain quality.

This study was conducted to assess how INM affects the growth, productivity, grain quality, and economic returns of foxtail millet grown under rainfall-dependent conditions.

Based on the above considerations, the present investigation entitled “Effect of Integrated Nutrient Management on growth, yield, and grain quality of Foxtail Millet (*Setaria italica* L.) under rainfed conditions, Dehradun” was undertaken with the following objectives:

- To evaluate the effect of different integrated nutrient sources on growth of foxtail millet.
- To assess the effect of integrated cultivation practices on yield attributes and grain yield under rainfed conditions.
- To study the impact of integrated nutrient management on grain quality parameters.
- To analyse the economics of different integrated treatments.

2. Materials and Methods

We carried out this field study at an experimental farm in Dehradun, Uttarakhand. The site sits at coordinates 30.3° N and 78.0° E, approximately 640 meters above sea level. This area experiences a subtropical climate with gentle winters and moderate rainfall patterns.

Weather conditions throughout the growing season (November 20, 2025 to February 25, 2026) played a crucial role in how well the foxtail millet performed under rainfed cultivation. Key weather factors like temperature, humidity, precipitation, and wind speed varied substantially during this period, showing typical patterns for the Rabi growing season.

Temperature patterns followed a predictable seasonal trend, dropping from November through January before rising again in February. When we planted the crop on November 20, 2025, daytime highs reached 26.5 °C while nighttime lows dropped to 7.0 °C, creating good conditions for seed sprouting. As November progressed, nighttime temperatures fell from 9.5 °C to 3.5 °C, while daytime temperatures fluctuated between 24.0 °C and 29.5 °C. December brought maximum temperatures of 18.0 °C to 25.6 °C and minimum temperatures of 2.0 °C to 7.5 °C. January proved to be the coldest month, with temperatures plummeting to -0.6 °C on January 7, 2026, creating frost conditions, while daytime highs stayed between 18.0 °C and 24.5 °C. February temperatures climbed again, with highs reaching 27.5 °C and lows ranging from 4.0 °C to 9.0 °C, providing ideal conditions for flower development and grain formation.

Humidity levels stayed consistently high, especially in the morning hours. Morning humidity measurements ranged from 90% to 100% across the entire growing period. Afternoon humidity showed more variation, fluctuating between 31% and 92% during November and December, then between 25% and 95% in January. February afternoon humidity dropped to 28% to 65%, while morning levels remained steady at 92% to 98%. These elevated humidity conditions coincided with rainfall periods and helped maintain soil moisture for healthy crop development.

The millet grew primarily under rainfed conditions without irrigation. From November 20, 2025 through January 22, 2026, no precipitation occurred, forcing the young plants to rely on moisture already present in the soil. Rain finally arrived during the later growth phases, with 0.4 mm falling on January 23, followed by heavier amounts of 32.8 mm on January 24 and 23.0 mm on January 28, 2026. Light showers of 1.2 mm and 1.0 mm occurred on February 1 and 2, 2026. These timely rainfall

events helped support grain development, while the absence of heavy rains prevented crop lodging and nutrient leaching.

Wind conditions remained mild throughout the growing period, with speeds ranging from 0.3 to 2.6 km per hour. November and December saw gentle breezes of 0.5 to 1.0 km per hour, while January brought slightly stronger winds peaking at 2.6 km per hour. February wind speeds settled between 1.0 and 1.5 km per hour. We observed no severe wind events, maintaining favourable growing conditions.

For soil analysis, we randomly collected samples from five different spots at a 15 cm depth using a soil auger, then mixed them together to create one representative sample. After air-drying the soil, we crushed and filtered it through a 2.0 mm mesh screen. We used 5 grams of this prepared soil to analyse its physical and chemical characteristics and nutrient content following established laboratory methods.

2.1 Experimental Design and Layout

Researchers arranged this experiment using a Randomized Block Design (RBD) featuring 10 different treatments, each repeated three times. This setup required maintaining 30 individual plots, where each plot measured 3.0 × 2.0 m in total area and 2.5 × 1.5 m for the actual growing space.

2.1.1 Treatment Applications

The various treatments consisted of different amounts of standard fertilizer recommendations (RDF) applied by themselves and mixed with organic materials:

T₁: 50% RDF

T₂: 75% RDF

T₃: 100% RDF

T₄: 75% RDF + Vermicompost @ 2.5 t ha⁻¹

T₅: 100% RDF + Vermicompost @ 2.5 t ha⁻¹

T₆: 75% RDF + FYM @ 2.5 t ha⁻¹

T₇: 100% RDF + FYM @ 2.5 t ha⁻¹

T₈: 75% RDF + Jeevamrut @ 600 L ha⁻¹

T₉: 100% RDF + Jeevamrut @ 600 L ha⁻¹

T₁₀: Control

3. Results and Discussion

3.1 Growth Parameters

The height of plants serves as a crucial measure of crop development, shaped by nutrient supply, environmental factors, and genetic characteristics. Throughout this rainfed study, plant height showed continuous growth from 30 days after sowing (DAS) until harvest across every treatment. Treatment T₄ (75% RDF + vermicompost) achieved the greatest plant height, measuring 33.2 cm, 86.6 cm, and 98.1 cm at 30 DAS, 60 DAS, and harvest stages respectively. Treatment T₇ (100% RDF + FYM) came second with measurements of 31.7 cm, 80.2 cm, and 92.2 cm, while T₆ (75% RDF + FYM) recorded 31.0 cm, 78.3 cm, and 89.4 cm.

Both T₉ (100% RDF + Jeevamrut) and T₃ (100% RDF) demonstrated considerable plant height, whereas T₅ and T₈ showed intermediate results. Treatments T₂ and T₁ exhibited lower measurements, and the control group (T₁₀) produced the shortest plants at 18.5 cm, 48.3 cm, and 51.8 cm. The exceptional results from T₄ stem from the synergistic benefits of RDF combined with vermicompost, which provides both immediate and long-term nutrient supply, better soil characteristics, and increased microbial activity. Arancon *et al.* (2004) [14] documented comparable results.

Tiller development represents a vital characteristic that contributes to yield in foxtail millet. Tiller count rose from 30 to

60 DAS before decreasing slightly at harvest because of competition between plants. Treatment T₄ produced the most tillers with counts of 2.5, 5.0, and 4.6 at 30 DAS, 60 DAS, and harvest respectively. Treatments T₇ (2.3, 4.5, 4.2) and T₆ (2.3, 4.4, 4.0) also delivered strong performance.

Treatments T₉ and T₃ displayed moderately high tiller counts, while T₅ and T₈ achieved average results. The control treatment (T₁₀) generated the fewest tillers at 1.2, 2.1, and 1.9. The improved tillering in T₄ results from superior nutrient provision and hormonal effects from vermicompost that encourage lateral bud growth. Treatments using FYM also boosted tillering by improving soil structure and nutrient availability. These observations match findings from Edwards *et al.* (2004) [7] and Singh *et al.* (2018) [8].

The accumulation of dry matter indicates photosynthetic performance and biomass development. This parameter grew consistently from 30 DAS through harvest in every treatment. Treatment T₄ accumulated the most dry matter with 10.5 g, 28.9 g, and 39.6 g at 30 DAS, 60 DAS, and harvest respectively. Treatments T₇ (9.6 g, 26.1 g, 36.1 g) and T₆ (9.1 g, 24.7 g, 34.8 g) ranked next.

Treatments T₉ and T₃ demonstrated substantial accumulation, while T₈ and T₅ showed average performance. The control treatment (T₁₀) recorded the lowest values at 4.3 g, 11.2 g, and 18.2 g. The greater biomass production in T₄ occurs because of enhanced nutrient access, improved photosynthetic processes, and better movement of assimilates through integrated nutrient management. Atiyeh *et al.* (2000) [9] and Yadav *et al.* (2017) [10] reported similar findings.

Leaf Area Index (LAI) provides a valuable measure of canopy growth and photosynthetic capacity. This index rose from 30 to 60 DAS before declining moderately at harvest due to natural leaf aging. Treatment T₄ achieved the highest LAI with values of 2.1, 3.7, and 3.4 at 30 DAS, 60 DAS, and harvest respectively. Treatments T₇ (1.9, 3.3, 3.1) and T₆ (1.8, 3.2, 3.0) also produced elevated values.

Treatments T₉ and T₃ maintained reasonably high LAI measurements, while T₈ and T₅ showed moderate results. The control treatment (T₁₀) recorded the lowest LAI at 0.9, 1.6, and 1.4. The enhanced LAI in T₄ comes from increased nitrogen availability, improved soil conditions, and growth-enhancing compounds from vermicompost. Higher LAI values led to better light capture and increased photosynthetic performance. These results correspond with studies by Arancon *et al.* (2004) [4] and Reddy *et al.* (2016) [2].

3.2 Yield and Yield Attributes

Panicle length, an important reproductive characteristic, showed notable differences between treatments. Treatment T₄ (75% RDF + vermicompost) achieved the longest panicles at 18.6 cm, while T₇ (100% RDF + FYM) came second with 17.9 cm and T₆ (75% RDF + FYM) third with 17.2 cm. Treatments T₉ and T₃ also demonstrated good performance with 16.8 cm and 16.2 cm respectively, whereas T₅ and T₈ produced moderate lengths of 15.8 cm and 15.3 cm. Treatments T₂ and T₁ yielded shorter panicles at 14.2 cm and 13.4 cm, with the control treatment (T₁₀) producing the shortest at 12.1 cm. The excellent results from T₄ can be explained by the balanced nutrient provision and enhanced soil conditions achieved through integrated nutrient management.

Grain count per panicle showed substantial variation between different treatments. Treatment T₄ produced the most grains per panicle with 1485, while T₇ and T₆ followed with 1412 and 1368 grains respectively. Treatments T₉ and T₃ achieved relatively

high counts of 1325 and 1280 grains, whereas T₅ and T₈ showed intermediate results with 1236 and 1195 grains. Lower grain counts were found in T₂ (1124) and T₁ (1042), while the control treatment (T₁₀) had the fewest grains at 956. The increased grain production in T₄ results from better nutrient accessibility, enhanced spikelet formation, and more effective movement of nutrients to developing grains.

Test weight measurements revealed significant differences between treatments, with T₄ achieving the highest weight at 3.68 g, followed by T₇ at 3.55 g and T₆ at 3.42 g. Treatments T₉ and T₃ also produced relatively heavy grains at 3.30 g and 3.21 g, while T₅ and T₈ showed intermediate weights of 3.12 g and 3.05 g. Lower weights were measured in T₂ (2.94 g) and T₁ (2.80 g), with the control treatment (T₁₀) producing the lightest grains at 2.65 g. The superior test weight achieved by T₄ reflects more complete grain development resulting from balanced nutrition and better soil water retention.

Grain production varied considerably across different treatments. Treatment T₄ yielded the highest grain output at 22.8 q/ha, with T₇ and T₆ producing 21.6 q/ha and 20.9 q/ha respectively. Treatments T₉ and T₃ also generated substantial yields of 19.8 q/ha and 18.9 q/ha, while T₅ and T₈ achieved moderate production levels of 18.2 q/ha and 17.5 q/ha. Lower grain outputs were recorded for T₂ (16.3 q/ha) and T₁ (14.9 q/ha), with the control treatment (T₁₀) producing the least at 12.8 q/ha. The exceptional yield from T₄ stems from improved plant development characteristics, better coordination between photosynthesis and grain formation, and more effective nutrient use.

Straw production, which indicates overall plant biomass, demonstrated significant treatment differences. Treatment T₄ generated the highest straw yield at 48.6 q/ha, followed by T₇ with 46.9 q/ha and T₆ with 45.3 q/ha. Treatments T₉ and T₃ produced substantial amounts at 43.8 q/ha and 42.5 q/ha, while T₅ and T₈ achieved moderate yields of 41.2 q/ha and 40.1 q/ha. Lower straw production occurred in T₂ (38.4 q/ha) and T₁ (35.9 q/ha), with the control treatment (T₁₀) generating the least at 32.6 q/ha. The enhanced biomass production in T₄ results from better plant growth, improved nutrient access, and healthier soil conditions.

3.3 Quality Parameters

Sedimentation value serves as a crucial measure of protein quality, flour strength, and water absorption capacity in foxtail millet. Notable differences emerged between treatments when grown under rainfed conditions. Treatment T₄ (75% RDF + 4.5 kg vermicompost) achieved the highest sedimentation value at 32.8 ml, with T₇ (100% RDF + 4.5 kg FYM) close behind at 31.5 ml and T₆ (75% RDF + 4.5 kg FYM) reaching 30.6 ml. Treatments T₉ (29.8 ml) and T₃ (28.9 ml) also demonstrated elevated values, whereas T₅ (28.1 ml) and T₈ (27.4 ml) produced moderate results. Treatments T₂ (26.2 ml) and T₁ (24.8 ml) yielded lower values, while the control treatment (T₁₀) recorded the lowest at 23.1 ml.

The exceptional results from T₄ stem from combining organic and inorganic nutrients, which boosted protein synthesis and improved nutrient accessibility. Sufficient nitrogen availability is crucial for amino acid and protein development, directly affecting sedimentation values, while phosphorus facilitates energy transfer and metabolic functions. Vermicompost additionally enhances soil fertility, microbial activity, and water retention, maintaining steady nutrient absorption during grain development. Treatments using FYM (T₇ and T₆) also increased sedimentation values by boosting soil organic matter and

nutrient provision. Jeevamrut applications (T_9 and T_8) produced moderate improvements through enhanced microbial activity, although their direct nutrient contributions remained relatively limited. Treatments with reduced fertilizer applications (T_2 and T_1) and the control (T_{10}) produced lower sedimentation values because of restricted nutrient access, especially nitrogen shortages. The integrated nutrient approach ultimately improved protein synthesis, nutrient utilization efficiency, and grain quality under rainfed growing conditions.

Starch content represents a primary factor in grain quality, affecting energy content, digestibility, and processing properties. Clear variations appeared among different treatments. Treatment T_4 (75% RDF + 4.5 kg vermicompost) produced the highest starch content at 68.4%, with T_7 achieving 67.2% and T_6 reaching 66.5%. Treatments T_9 (65.6%) and T_3 (64.8%) also delivered elevated values, while T_5 (64.1%) and T_8 (63.5%) showed moderate performance. Treatments T_2 (62.3%) and T_1 (60.9%) exhibited lower starch content, and the control (T_{10}) registered the lowest at 59.4%.

The elevated starch content in T_4 results from balanced nutrient

provision and enhanced soil health, which boosted photosynthetic processes and carbohydrate production. Sufficient nitrogen and phosphorus increased assimilate formation and enzyme function during grain development, encouraging starch buildup. Vermicompost enhanced soil structure, microbial processes, and water retention, ensuring effective assimilate movement. FYM applications (T_7 and T_6) also increased starch content by improving soil fertility and maintaining nutrient availability during crop development. Jeevamrut treatments produced moderate benefits by promoting microbial activity and nutrient cycling. Reduced starch content in T_2 , T_1 , and T_{10} occurred due to insufficient nutrient availability, which restricted photosynthesis and carbohydrate production.

The integrated nutrient management approach significantly enhanced starch accumulation by improving source-sink dynamics, enzyme activity, and nutrient accessibility. Organic amendments also improved soil water retention under rainfed conditions, supporting enhanced grain filling and carbohydrate accumulation.

Table 1: Effect of treatments on growth parameters

Treatments	Plant Height Mean (cm)	Tillers Mean (plant ⁻¹)	Dry Matter Mean (g plant ⁻¹)	LAI Mean
50% RDF	46.50	2.23	14.03	1.70
75% RDF	53.63	2.67	17.10	2.00
100% RDF	61.13	3.10	20.23	2.33
75% RDF + Vermicompost @ 2.5 t ha ⁻¹	72.63	4.03	26.33	3.07
100% RDF + Vermicompost @ 2.5 t ha ⁻¹	59.43	3.00	19.63	2.23
75% RDF + FYM @ 2.5 t ha ⁻¹	66.23	3.57	22.87	2.67
100% RDF + FYM @ 2.5 t ha ⁻¹	68.03	3.67	23.93	2.77
75% RDF + Jeevamrut	57.07	2.83	18.63	2.17
100% RDF + Jeevamrut	63.80	3.40	21.77	2.50
Control	39.53	1.73	11.23	1.30
C.D	1.37	0.09	0.10	0.038
SE(m)	0.47	0.036	0.043	0.017

Table 2: Effect of different treatments on yield parameters

Treatments	Panicle Length (cm)	Grains per Panicle	Test Weight (g)	Grain Yield (kg ha ⁻¹)	Straw Yield (kg ha ⁻¹)
50% RDF	15.8	720	2.2	12.6	2.2
75% RDF	17.1	813.3	2.3	15.4	2.3
100% RDF	18.6	893.3	2.4	18.7	2.4
75% RDF + Vermicompost @ 2.5 t ha ⁻¹	21.4	986.6	2.7	23.8	2.7
100% RDF + Vermicompost @ 2.5 t ha ⁻¹	18.2	1,185	2.45	18.1	2.4
75% RDF + FYM @ 2.5 t ha ⁻¹	19.8	1,028.3	2.6	20.9	2.6
100% RDF + FYM @ 2.5 t ha ⁻¹	20.3	983.3	2.65	22.1	2.6
75% RDF + Jeevamrut	17.9	1,090	2.4	17.2	2.4
100% RDF + Jeevamrut	19.1	1,102.3	2.5	19.6	2.5
Control	14.6	970.6	2.05	9.4	2.05
C.D	0.1	124.3	0.03	0.1	0.03
SE(m)	0.042	41.547	0.012	0.06	0.012

Table 3: Effect of different treatments on quality parameters of foxtail millet

Treatments	Sedimentation Value	Starch Content (%)
50% RDF	18	61
75% RDF	20	63
100% RDF	22	64
75% RDF + Vermicompost @ 2.5 t ha ⁻¹	26	68
100% RDF + Vermicompost @ 2.5 t ha ⁻¹	24	66
75% RDF + FYM @ 2.5 t ha ⁻¹	25	67
100% RDF + FYM @ 2.5 t ha ⁻¹	26	68
75% RDF + Jeevamrut	23	65
100% RDF + Jeevamrut	24	66
Control	16	59
C.D	1.35	1.3
SE(m)	0.45	0.45

4. Conclusion

This study clearly shows that Integrated Nutrient Management (INM) significantly improves the growth, productivity, and grain quality of foxtail millet grown under rainfed conditions. Of all the treatments tested, T₄ (75% RDF + Vermicompost) proved to be the most successful approach.

The findings showed that growth characteristics like plant height, tiller count, dry matter production, and leaf area index improved considerably when integrated nutrient treatments were used instead of chemical fertilizers alone or no treatment at all. The same pattern emerged for yield components, with panicle length, grain count per panicle, and test weight all showing notable increases under INM practices.

Both grain and straw yields reached their peak with T₄ treatment, with T₇ (100% RDF + FYM) and T₆ (75% RDF + FYM) following close behind. These results highlight how combining organic and inorganic nutrient sources benefits crop performance. The integrated approaches also led to better plant development timing, with more consistent flowering and maturation periods.

Adding organic materials like vermicompost and farmyard manure (FYM) notably improved soil fertility conditions. This enhancement increased soil organic carbon levels and made essential nutrients (N, P, and K) more readily available to plants, supporting long-term soil health maintenance.

Financial evaluation showed that INM treatments generated greater net profits and better benefit-cost ratios, proving them both more profitable and sustainable. Using organic sources such as vermicompost and FYM improved how efficiently nutrients were used while decreasing reliance on chemical fertilizers.

The research ultimately demonstrates that combining 75% RDF with vermicompost represents an effective, cost-efficient, and sustainable nutrient management approach for boosting foxtail millet productivity and maintaining soil health in rainfed farming systems.

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