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Nitrogen management through organic sources: effects on yield, nutrient uptake and nitrogen balance in rainfed barnyard millet (*Echinochloa frumentacea L.*)

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Abstract
Barnyard millet (*Echinochloa frumentacea* L.) is recognized as a hardy, climate-resilient minor millet that performs well under rainfed conditions and plays an important role in food and nutritional security in marginal ecosystems. Nitrogen management through organic inputs is essential not only for sustaining productivity but also for enhancing nutrient uptake and maintaining long-term soil fertility. To evaluate the influence of organic sources of nitrogen on yield, nutrient uptake and nitrogen balance in rainfed barnyard millet, a field experiment was conducted during the *kharif* season of 2024 at Organic Farming Research Institute, University of Agricultural Sciences, Raichur, Karnataka, India. The study compared different levels of nitrogen through farmyard manure (FYM) and vermicompost in combination with organic liquid formulations such as jeevamrutha and gokrupamrutha. The experiment was laid out in a Randomized Complete Block Design (RCBD) with twelve treatments and three replications. Significant improvements in grain yield, straw yield and NPK uptake were recorded with the treatment receiving recommended FYM @ 5t ha^{-1} + *Azospirillum* seed treatment *fb* soil application of jeevamrutha @ 500 l ha^{-1} *fb* gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS. This treatment resulted in the maximum percentage increase in grain yield (143.08%) and straw yield (145.59%) over the absolute control, along with significantly higher nitrogen (28.35 kg ha^{-1}), phosphorus (14.54 kg ha^{-1}) and potassium (18.36 kg ha^{-1}) uptake at harvest. The study demonstrates that organic nitrogen management strategies significantly improve yield performance and nutrient assimilation, while ensuring better nitrogen balance and soil fertility, thereby advancing the sustainability of barnyard millet production under rainfed ecosystems.

Keywords: Barnyard millet, FYM, Vermicompost, Grain yield, Nutrient uptake

Introduction
The intensive use of synthetic fertilizers in modern agriculture has led to nutrient imbalances, soil degradation and environmental concerns, highlighting the need for sustainable alternatives (Kumar *et al*., 2019) [8]. Organic nutrient management has emerged as a viable solution, restoring soil fertility, improving crop productivity and enhancing long-term agricultural sustainability. Organic inputs such as FYM, vermicompost and liquid bio-formulations like jeevamrutha and gokrupamrutha enrich soil health, stimulate microbial activity and enhance plant resilience. Additionally, biofertilizers such as *Azospirillum* play a key role in biological nitrogen fixation, further improving nutrient uptake and yield performance (Bashan *et al*., 2020) [3].

Millets, often termed "nutri-cereals," are climate-resilient grains valued for their nutritional richness and adaptability to rainfed conditions. Among them, barnyard millet is a hardy small millet grown under marginal environments, particularly in Asia. It contributes to food and nutritional security of resource-poor farmers due to its ability to thrive in low-input systems and its superior nutritional quality, including high dietary fiber and easily digestible protein (Hadimani *et al*., 1993; Banerjee and Maitra, 2020) [6, 2].

Despite its resilience and nutritional importance, the productivity of barnyard millet remains low, mainly due to inadequate nutrient management under rainfed conditions. While the benefits of organic manures and liquid formulations have been demonstrated in other crops, systematic

studies on their role in nutrient uptake and yield performance of barnyard millet are limited. Therefore, the present investigation was undertaken to evaluate the influence of organic nitrogen management through FYM, vermicompost, biofertilizers and organic liquid formulations on yield, nutrient uptake, and soil fertility of barnyard millet under rainfed conditions.

Materials and methods

Experimental Site

The field experiment was carried out during *kharif*, 2024 at the Organic Farming Research Institute, University of Agricultural Sciences, Raichur. The geographical location of the experimental site was 16^0 12'N latitude and 77^0 20' E longitude and at an altitude of 389 m above mean sea level (MSL). The experimental soil was clay loam texture with pH (7.75), electrical conductivity (EC) 0.32 dS m^{-1}, organic carbon (0.72%) and low in available nitrogen (156.35 kg ha^{-1}), high in available phosphorus (36.24 kg ha^{-1}) and high in available potassium (348.86 kg ha^{-1}).

Experimental Details and Treatments

The experiment consisted of twelve treatments involving different organic nutrient management practices (Table 1). Farmyard manure (FYM), vermicompost and *Azospirillum* biofertilizer were obtained from the Organic Farming Research Institute, UAS Raichur. Jeevamrutha and gokrupamrutha were freshly prepared one week prior to application. The barnyard millet was sown at a spacing of 30 cm × 10 cm in plot sizes of 4.8 m × 3.6 m using the "HU-1" variety, sown at a depth of 2 cm sides of ridges. The organic manures were added 15 days prior to the date of sowing according to the treatment specifications and mixed thoroughly into the soil.

Table 1: Treatment details

T_1: 100% N through FYM
T_2: 100% N through vermicompost
T_3: 75% N through FYM + 25%N through vermicompost
T_4: 50% N through FYM + 50%N through vermicompost
T_5: 75% N through FYM + *Azospirillum* seed treatment
T_6: 50% N through FYM + *Azospirillum* seed treatment
T_7: 75% N through FYM + soil application of jeevamrutha @ 500 l ha^{-1}
T_8: 50% N through FYM + soil application of jeevamrutha @ 500 l ha^{-1}
T_9: 75% N through FYM + gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS
T_{10}: 50% N through FYM + gokrupamrutha spray @ 125l ha^{-1} at 30 DAS and 45 DAS
T_{11}: Recommended FYM @ 5t ha^{-1} + *Azospirillum* seed treatment *fb* soil application of jeevamrutha @ 500 l ha^{-1} *fb* gokrupamrutha spray @ 125 l ha^{-1} at 30DAS and 45 DAS
T_{12}: Absolute control

Nutrient Analysis of Organic Inputs

Before the initiation of the experiment, FYM, vermicompost, jeevamrutha and gokrupamrutha were analyzed for their nutrient composition and the results are presented in Table 2.

Table 2: Nutrient content of different organic manures

Sl. No.	Particulars	Nitrogen (%)	Phosphorus (%)	Potassium (%)
1.	Vermicompost	1.40	0.72	0.83
2.	FYM	0.40	0.23	0.61
3.	Jeevamrutha	0.98	0.34	1.11
4.	Gokrupamrutha	0.32	0.28	0.67

Grain and stover yield were recorded after drying to the recommended moisture level from the net plot and expressed in kg ha^{-1}.

$$\text{Nutrient uptake (kg ha}^{-1}) = \left(\frac{\text{Nutrient concentration (\%)} \times \text{Biomass (kg ha}^{-1})}{100} \right)$$

Nitrogen balance sheet of the soil

Nitrogen balance sheets were worked out for available N in post harvest soil on the basis of the following parameters, adopting the procedure outlined by Sadandan and Mahapatra (1973).

1. Initial status of nutrient in soil (A)
2. Total amount of nutrient added through manures and fertilizers (B)
3. Amount of nutrient removed by the crop or uptake (C)
4. Expected nutrient balance (D) = (A+B) -C
5. Available nutrient of soil after the experiment (E)
6. Actual loss (-) or gain (+) = (E - A) kg ha^{-1}

Following the statistical analysis methods outlined by Gomez and Gomez (2010) [5], were examined the data collected on various characters involved in the study. Whenever the analysis revealed statistically significant differences between the treatments, critical differences (CD) was calculated at 0.05 probability level to compare the groups.

Results and Discussion

Grain and straw yield (kg ha^{-1})

Nitrogen management through different sources significantly influenced the grain and straw yield of barnyard millet (Table 3). Application of recommended FYM @ 5 t ha^{-1} along with *Azospirillum* seed treatment followed by soil application of jeevamrutha @ 500 l ha^{-1} and foliar spray of gokrupamrutha @ 125 l ha^{-1} at 30 and 45 DAS (T_{11}) recorded the highest grain and straw yields (1704 and 3345 kg ha^{-1}, respectively), which were significantly superior to all other treatments. In contrast, the absolute control treatment (T_{12}) registered the lowest grain and straw yields (701 and 1362 kg ha^{-1}, respectively).

The improved yield could be attributed to the combined effect of FYM in improving soil fertility, *Azospirillum* seed treatment enhancing nutrient uptake, jeevamrutha enriching microbial activity and nutrient mineralization and gokrupamrutha supplying essential micronutrients along with growth-promoting hormones such as auxins, gibberellins and cytokinins. This

integrated nutrient management approach thus proved highly effective in enhancing productivity of barnyard millet. These results were in conformity with the findings of Patel *et al.* (2021) [10] and Ashok (2023) [1].

Nutrient uptake (kg ha^{-1})

Influence of nitrogen management through organic sources on N, P and K uptake at harvest is detailed in Table 4. Among the different organic sources, application of recommended FYM @ 5t ha^{-1} + *Azospirillum* seed treatment *fb* soil application of jeevamrutha @ 500 l ha^{-1} *fb* gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS (T_{11}) recorded significantly higher N, P and K uptake at harvest (28.35, 14.54 and 18.36 kg ha^{-1}, respectively) as compared to other treatments. Significantly lower nitrogen uptake at harvest (13.24, 6.57 and 9.32 kg ha^{-1}, respectively) was observed in absolute control (T_{12}).

The increased nitrogen uptake can be attributed to improved soil nitrogen availability, enhanced biological nitrogen fixation, stimulated root growth and efficient nitrogen assimilation. Higher phosphorus uptake may be due to increased availability of soluble phosphorus, stimulation of phosphate-solubilizing microbes and better root development. Similarly, increased potassium uptake could be linked to enhanced solubilization of fixed potassium by organic acids and microbes, improved root growth for effective absorption and favorable changes in soil physical and chemical properties resulting from the integrated application of FYM, *Azospirillum*, jeevamrutha and gokrupamrutha. These results were in conformity with the findings of Gowthamchand and Soumya (2019) and Javiya *et al.* (2022) [7].

Nitrogen balance in soil

Application of recommended FYM @ 5t ha^{-1} + *Azospirillum* seed treatment *fb* soil application of jeevamrutha @ 500 l ha^{-1} *fb* gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS (T_{11}) registered higher nitrogen gain (+2.3 kg ha^{-1}) as compared to other treatments. Whereas, absolute control (T_{12}) reported higher nitrogen loss (-50.3 kg ha^{-1}). However, higher nitrogen gain due to enhanced microbial activity from *Azospirillum* and jeevamrutha, which improved nitrogen retention and uptake. In contrast, the absolute control (T_{12}) lacked these inputs, led to higher nitrogen loss through leaching and volatilization.

Table 3: Grain yield, straw yield and per cent increase of grain yield over absolute control as influenced by organic sources of nitrogen management in barnyard millet

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Per cent increase of grain yield over absolute control
T_1: 100% N through FYM	1413	2812	101.56
T_2: 100% N through vermicompost	1526	3029	117.68
T_3: 75% N through FYM + 25% N through vermicompost	1446	2843	106.27
T_4: 50% N through FYM + 50% N through vermicompost	1460	2914	108.27
T_5: 75% N through FYM + *Azospirillum* seed treatment	1355	2737	93.29
T_6: 50% N through FYM + *Azospirillum* seed treatment	1156	2342	64.90
T_7: 75% N through FYM + soil application of jeevamrutha @ 500 l ha^{-1}	1395	2761	99.00
T_8: 50% N through FYM + soil application of jeevamrutha @ 500 l ha^{-1}	1159	2387	65.33
T_9: 75% N through FYM + gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS	1167	2420	66.47
T_{10}: 50% N through FYM + gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS	982	1986	40.08
T_{11}: Recommended FYM @ 5t ha^{-1}+ *Azospirillum* seed treatment *fb* soil application of jeevamrutha @ 500 l ha^{-1} *fb* gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS	1704	3345	143.08
T_{12}: Absolute control	701	1362	-
S.Em. ±	58	107	-
C. D. (P=0.05)	172	313	-

Table 4: Uptake of nitrogen, phosphorus and potassium as influenced by organic sources of nitrogen management in barnyard millet

Treatments	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
T_1: 100% N through FYM	24.03	12.45	15.84
T_2: 100% N through vermicompost	25.16	13.02	16.65
T_3: 75% N through FYM + 25% N through vermicompost	24.23	12.58	15.98
T_4: 50% N through FYM + 50% N through vermicompost	24.94	12.89	16.12
T_5: 75% N through FYM + *Azospirillum* seed treatment	23.48	12.06	15.23
T_6: 50% N through FYM + *Azospirillum* seed treatment	19.91	10.09	13.05
T_7: 75% N through FYM + soil application of jeevamrutha @ 500 l ha^{-1}	23.87	12.24	15.42
T_8: 50% N through FYM + soil application of jeevamrutha @ 500 l ha^{-1}	20.19	10.28	13.21
T_9: 75% N through FYM + gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS	20.38	10.46	13.43
T_{10}: 50% N through FYM + gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS	16.75	8.35	11.25
T_{11}: Recommended FYM @ 5t ha^{-1} + *Azospirillum* seed treatment *fb* soil application of jeevamrutha @ 500 l ha^{-1} *fb* gokrupamrutha spray @ 125 l ha^{-1} at 30DAS and 45 DAS	28.35	14.54	18.36
T_{12}: Absolute control	13.24	6.57	9.32
S.Em. ±	0.99	0.52	0.59
C. D. (P=0.05)	2.91	1.51	1.72

Table 5: Nitrogen (N) balance sheet in soil (kg ha^{-1}) after harvest of barnyard millet as influenced by organic sources

Treatments	Initial N (A)	Amount of N added (B)	Crop uptake (C)	Expected N balance D = (A+B)-C	Available N after the experiment (E)	Actual loss (-) or gain (+) F= E-A
T_1: 100% N through FYM	156.4	20.0	24.0	152.3	141.9	-14.5
T_2: 100% N through vermicompost	156.4	20.0	25.2	151.2	143.1	-13.2
T_3: 75% N through FYM + 25% N through vermicompost	156.4	20.0	24.2	152.1	142.2	-14.2
T_4: 50% N through FYM + 50% N through vermicompost	156.4	20.0	24.9	151.4	142.9	-13.5
T_5: 75% N through FYM + *Azospirillum* seed treatment	156.4	15.0	23.5	147.9	141.1	-15.2
T_6: 50% N through FYM + *Azospirillum* seed treatment	156.4	10.0	19.9	146.4	129.0	-27.4
T_7: 75% N through FYM + soil application of jeevamrutha @ 500 l ha^{-1}	156.4	19.9	23.9	152.4	141.6	-14.8
T_8: 50% N through FYM + soil application of jeevamrutha @ 500 l ha^{-1}	156.4	14.9	20.2	151.1	129.6	-26.8
T_9: 75% N through FYM + gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS	156.4	15.8	20.4	151.8	130.2	-26.2
T_{10}: 50% N through FYM + gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS	156.4	10.8	16.8	150.4	117.3	-39.1
T_{11}: Recommended FYM @ 5t ha^{-1} + *Azospirillum* seed treatment *fb* soil application of jeevamrutha @ 500 l ha^{-1} *fb* gokrupamrutha spray @ 125 l ha^{-1} at 30 DAS and 45 DAS	156.4	25.7	28.4	153.7	158.7	+2.3
T_{12}: Absolute control	156.4	0.0	13.2	143.1	106.1	-50.3

Conclusion

The study showed that integrated organic nitrogen management significantly improved yield, nutrient uptake and soil fertility in barnyard millet under rainfed conditions. The combined use of FYM, *Azospirillum*, jeevamrutha, and gokrupamrutha proved most effective, ensuring higher productivity with better nitrogen balance. These practices highlight the role of organic inputs in sustaining soil health and promoting sustainable millet production.

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