International Journal of Agriculture and Plant Science
www.agriculturejournal.in
Online ISSN: 2664-7664, Print ISSN: 2664-7656
Received: 16-02-2025, Accepted: 17-03-2025, Published: 01-04-2025
Volume 7, Issue 2, 2025, Page No. 43-48

Comparative assessment of microbial consortium and diverse farming practices on Ragi (*Eleusine Coracana*) growth and yield under field condition

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Abstract
The present study evaluates the impact of microbial consortium application on the growth and yield of ragi (*Eleusine coracana*) with different farming practices in field conditions. Conventional, organic and natural farming methods were assessed based on plant growth parameters, yield attributes and soil biological properties. The results showed that microbial consortium application significantly improved plant height, tiller production, nutrient uptake, and yield than control. Among the treatments, the highest yield was recorded in the recommended dose of fertilizer (RDF), followed by organic farming with vermicompost and farmyard manure (FYM). The microbial consortium contributed to enhanced soil microbial populations and their activities, leading to better nutrient cycling and overall soil health. It also facilitated improved soil structure, increased nutrient bioavailability, and stimulated root development, resulting in greater plant vigour. Organic farming, particularly with vermicompost, promoted higher microbial diversity and beneficial rhizosphere interactions. These findings suggest that microbial consortia can serve as an eco-friendly alternative to synthetic fertilizers, supporting sustainable agriculture while maintaining high crop productivity.

Keywords: Microbial consortium, organic farming, soil health, sustainable agriculture.

Introduction
Ragi (*Eleusine coracana*), a highly nutritious millet, is widely cultivated in semi-arid regions due to its adaptability to drought-prone environment and low soil fertility. However, intensive conventional farming practices that depend on synthetic fertilizers have led to soil degradation, decreased microbial diversity and long-term sustainability challenges. These practices contribute to soil compaction, nutrient depletion and reduced organic matter content, leading to declining yields over time. Additionally, the excessive use of chemical inputs has disrupted soil microbial communities, negatively affecting nutrient cycling and soil health. To counteract these challenges, alternative sustainable approaches are necessary for improving soil fertility and crop productivity.

The use of microbial consortia, composed of plant growth-promoting microorganisms (PGPMs), offers an innovative approach to enhancing soil fertility and optimizing crop performance. These beneficial microbes facilitate biological nitrogen fixation, phosphorus solubilization, hormone production and disease suppression, collectively promoting plant growth and increasing yield potential. Microbial consortia have been recognized for their ability to improve nutrient availability, enhance soil structure and stimulate root development. These microorganisms including bacteria and fungi, establish synergistic relationships with plant roots, enhancing nutrient uptake and resilience against environmental stress. In organic and natural farming systems, microbial consortia work in conjunction with organic amendments like FYM and vermicompost, fostering microbial balance and increasing enzymatic activity (Das *et al.,* 2023). Additionally, microbial inoculants enhance soil aggregation, suppress harmful pathogens and improve soil aeration, creating a favourable environment for plant growth. Despite the growing interest in sustainable agricultural practices, limited research has focused on the role of microbial consortia in ragi cultivation under different farming systems. This study aims to evaluate the effects of microbial consortia on ragi growth and yield across varied farming practices, highlighting their potential as a sustainable alternative to conventional chemical fertilizers. The findings will contribute to advancing sustainable agricultural practices by formulating effective soil and crop management strategies for ragi cultivation.

Material and Methods
Microbial consortium preparation
Three efficient earthworm gut bacterial isolates, namely EGNF-12, EGCF-1, and EGCF-10, were selected for microbial consortium preparation based on their plant growth-promoting traits. These isolates exhibited key attributes such as phosphate solubilization, nitrogen fixation and production of phytohormones. To formulate the consortium, the isolates were cultured separately in nutrient broth under optimal growth conditions. Once they reached the desired cell density, the cultures were mixed in equal proportion to ensure a balanced microbial composition. UASB microbial consortium (developed by Biofertilizer Scheme, UAS, GKVK, Bengaluru) was used as a reference. The prepared consortium was then subjected to further evaluation.

Evaluation of Microbial consortium and different farming practices on ragi under field condition
The microbial consortium was evaluated for plant growth and yield by taking ragi [*Eleusine coracana* (L.) Gaertn] as

the test crop under field condition. The details are given in Table 1. The field experiment was conducted at Bioenergy Research and Quality Assurance Laboratory, UAS, GKVK, Bengaluru-65, using ragi (*Eleusine coracana* (L.) Gaertn) variety ML-322 in *Kharif*-2024. The study followed a Randomized Complete Block Design (RCBD) with eight treatments and three replications. The gross plot size was 1.8 m × 1.0 m, while the net plot size was 1.2 m × 0.8 m. The crop was sown with a spacing of 30 cm × 10 cm.

Table 1: Treatment details for evaluation of microbial consortium on growth and yield of ragi under field condition

Treatments	Description
T_1: Absolute control	Only sowing of seeds. All other inputs and practices are nil
T_2: RDF	Seed treatment with *Azospirillum* sp., FYM - 7.5 t/ha, NPK - 100:50:50 kg/ha, Pre-emergent herbicide Pendimethalin 30 EC @ 1 kg a.i/ha, Micronutrients Zinc @ 12.5 kg/ha and Borax @ 10 kg/ha, Hand weeding at 20 and 40 DAS
T_3: Organic farming practices (FYM)	Seed treatment with *Azospirillum* sp., FYM - N eq. (100 kg N/ha), Hand weeding at 20 and 40 DAS,
T_4: Organic farming practices (Vermicompost)	Seed treatment with *Azospirillum* sp., Vermicompost - N eq. (100 kg N/ha), Hand weeding at 20 and 40 DAS,
T_5: Natural farming practices	Seed treatment - Beejamrutha, Ghanajeevamrutha @ 1000 kg/ha, Jeevamrutha application - 500 L/ha at 15 days interval, Hand weeding at 20 and 40 DAS,
T_6: Farmers' practices	No seed treatment, FYM - 5 t/ha, 2.5 bags DAP (125 kg/ha), 2.5 bags urea (112.5 kg/ha), Hand weeding at 20 and 40 DAS
T_7: Microbial consortium	Seed treatment with microbial consortium, FYM - 7.5 t/ha, Application of microbial consortium (carrier based) @ 10 kg/ha, Hand weeding at 20 and 40 DAS
T_8: UASB microbial consortium (reference)	Seed treatment with UASB microbial consortium, FYM - 7.5 t/ha, Application of UASB microbial consortium (carrier based) @ 10 kg/ha, Hand weeding at 20 and 40 DAS

Plant growth parameters

Plant height (cm) and Number of tillers per hill

Plant height (cm) and the number of tillers per hill were recorded at different growth stages. Plant height was measured from the ground level to the base of the fully opened leaf at 30 and 60 DAS, and from the base to the panicle at 90 DAS and harvest. Similarly, the number of tillers per hill was counted at 30, 60 DAS, and harvest on five randomly selected plants, and the average was expressed accordingly.

Yield attributes of finger millet at harvest

Yield attributes of finger millet at harvest were recorded from five selected tagged plants. The number of productive tillers per plant was determined by averaging the total productive tillers. Ear head length was measured and ear head weight was recorded by weighing. Grain weight per ear head was obtained after drying and threshing. The average number of fingers per ear head was counted across the sampled plants.

Grain yield (kg ha^{-1})

The grain yield obtained from each net plot area was sun dried for 4-6 days in the threshing yard to storage moisture. After threshing, grains were separated, cleaned and weighed. Later the grain yield per net plot was computed on hectare basis and expressed in kilogram per hectare.

Straw yield (kg ha^{-1})

Straw yield from the net plot area was recorded after sun drying for 8-10 days and straw yield per net plot was computed on hectare basis and expressed in kilogram per hectare.

Enumeration of microbial population

The enumeration of total bacteria, fungi and actinomycetes in the soil samples was carried out by following the standard dilution and plate count technique. Nutrient agar for bacteria (10^{-6}), Martin's rose bengal agar for fungi (10^{-4}), Kuster's agar for actinomycetes (10^{-3}), were used for enumeration. The petri plates were incubated at 28±2°C for 2-5 days and population was expressed as log cfu/g of soil.

Available Nutrient status in soil

Available nitrogen was estimated using the alkaline permanganate method with micro-Kjeldahl (Subbiah and Asija, 1956) [14] and expressed as kg ha^{-1}. Available phosphorus was extracted using Olsen's or Bray's method and determined by the ascorbic acid method at 660 nm (Bray and Kurtz, 1945). Available potassium was extracted with neutral normal ammonium acetate and measured using a flame photometer (Jackson, 1973) [5], expressed as kg ha^{-1}.

Statistical analysis

The data obtained was analysed using one-way ANOVA test. The means were separated by Duncan's multiple range test (DMRT) at a significance level of $P<0.05$ using the WASP v2.0 software (https://ccari.icar.gov.in/wasp2.0/index.php) (Jangam and Thali, 2004) [6].

Results and discussion

The effect of microbial consortium and different farming practices on the growth of ragi was evaluated at different growth stages under field condition (Plate 1).

Plate 1: General view of ragi field experiment at 60 days after sowing

Plant height and number of tillers per hill

The effect of different farming practices on the plant height and number of tillers per hill of ragi at various growth stages (30 DAS, 60 DAS, and at harvest) were recorded and tabulated in Table 2. At 30 DAS, the highest plant height was observed in (T_2) RDF (40.82 cm), significantly outperforming other treatments, while the absolute control (T_1) showed the lowest height (29.24 cm). At 60 DAS, T_2 remained the highest (100.91 cm), followed by (T_4) Organic farming with vermicompost (98.29 cm). By harvest, T_2 recorded the highest height (122.21 cm), followed by T_4 (121.05 cm) and (T_3) Organic farming with FYM (114.08 cm), with T_1 having the lowest (95.12 cm). Tillers per hill followed a similar trend, with T_2 having the highest count at all stages, reaching 3.60 at harvest, followed by T_4 (3.00) and (T_6) Farmers' practices (3.40). The lowest tiller count at harvest was in T_1 (1.60). (T_7) Microbial consortium exhibited a moderate performance in both plant height and tiller count but was outperformed by RDF and organic treatments.

The increased growth parameters of ragi with RDF and organic treatment were due to enhanced nutrient availability, improved soil properties and additional nitrogen from atmospheric fixation and mineralization. RDF significantly outperformed other treatments by promoting microbial activity and creating a favourable rhizosphere. This facilitated better root growth, increased nutrient uptake and enhanced cell division and expansion, leading to greater plant height and a higher number of tillers (Meena and Gautam, 2005) [10].

Table 2: Effect of microbial consortium and different farming practices on growth of ragi at different stages under field condition

Treatments	Plant height (cm)			Number of tillers hill^{-1}		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1: Absolute control	29.24^{e}	78.84^{d}	95.12^{d}	1.00^{b}	1.40^{e}	1.60^{g}
T_2: Recommended dose of fertilizer (RDF)	40.82^{a}	100.91^{a}	122.21^{a}	1.20^{a}	2.40^{a}	3.60^{a}
T_3: Organic farming practices (N equivalent with FYM)	37.06^{bc}	93.06^{ab}	114.08^{ab}	1.00^{b}	2.00^{c}	2.80^{d}
T_4: Organic farming practices (N equivalent with vermicompost)	39.93^{ab}	98.29^{a}	121.05^{a}	1.20^{a}	2.20^{b}	3.00^{c}
T_5: Natural farming practices	32.09^{de}	94.02^{cd}	102.03^{cd}	1.00^{b}	1.60^{d}	1.80^{f}
T_6: Farmers' practices	36.88^{bc}	92.73^{ab}	113.64^{ab}	1.00^{b}	2.20^{b}	3.40^{b}
T_7: Microbial consortium	34.24^{cd}	87.93^{bc}	107.24^{bc}	1.00^{b}	1.40^{e}	2.00^{e}
T_8: UASB microbial consortium (Reference)	31.67^{de}	83.27^{cd}	101.03^{cd}	1.00^{b}	1.40^{e}	2.00^{e}

Note: DAS- days after sowing; Mean values followed by the same letter in each column are not significantly different from each other as determined by DMRT ($p<0.05$).

Yield components of finger millet at harvest

The impact of microbial consortium and different farming practices on the yield components of ragi showed significant differences across treatments (Table 3). T_2: Recommended dose of fertilizer (RDF) demonstrated the highest performance, achieving the significant values for all parameters, including number of productive tillers per hill (3.2), number of fingers per earhead (6.86), finger length (7.59 cm), earhead weight (6.78 g), and grain weight per earhead (5.48 g). Both T_3: Organic farming with FYM and T_4: Organic farming with vermicompost recorded 2.8 productive tillers per hill, 6.32 and 6.48 number of fingers per earhead, and grain weight of 5.25 g and 5.31 g. T_6: Farmers' practices also showed promising results, with 2.8 productive tillers, 6.46 fingers per earhead, and a grain weight of 5.41 g. T_7: Microbial consortium and T_8: UASB microbial consortium, showed moderate performance, with 1.8 productive tillers per hill, 5.74 and 5.58 number of fingers per earhead, and grain weights of 4.89 and 4.77g, respectively.

The improved yield attributes with RDF application may be due to enhanced dry matter production, supporting grain filling through increased leaf number and photosynthetic activity. Higher nitrogen fixation and nutrient solubilization from biofertilizers, combined with increased fertilizer levels, led to greater nutrient availability. This facilitated better growth and development of reproductive structures, ultimately enhancing the productivity of individual plants. Such observations were also recorded by researchers like Opera *et al.* (2017) [11], Yadav and Singh (2016) [15] and Patil *et al.* (2006) [12].

Table 3: Effect of microbial consortium and different farming practices on yield components of ragi.

Treatments	No. of productive tillers per hill	No. of fingers per earhead	Finger length (cm)	Ear head weight (g)	Grain weight per earhead (g)
T_1: Absolute control	1.6^{e}	5.36^{d}	5.92^{e}	5.21^{e}	4.17^{e}
T_2: Recommended dose of fertilizer (RDF)	3.2^{a}	6.86^{a}	7.59^{a}	6.78^{a}	5.48^{a}
T_3: Organic farming practices (N equivalent with FYM)	2.8^{b}	6.32^{b}	7.46^{ab}	6.56^{b}	5.25^{b}
T_4: Organic farming practices (N equivalent with vermicompost)	2.8^{b}	6.48^{b}	7.48^{ab}	6.64^{b}	5.31^{b}
T_5: Natural farming practices	1.8^{d}	5.63^{c}	6.66^{d}	5.86^{d}	4.69^{d}
T_6: Farmers' practices	2. 8^{b}	6.46^{b}	7.48^{ab}	6.71^{ab}	5.41^{ab}
T_7: Microbial consortium	1.8^{d}	5.74^{c}	6.94^{c}	6.11^{c}	4.89^{c}
T_8: UASB microbial consortium (Reference)	1.8^{d}	5.58^{cd}	6.77^{cd}	5.96^{cd}	4.77^{cd}

Note: Mean values followed by the same letter in each column are not significantly different from each other as determined by DMRT ($p<0.05$).

Grain and Straw yield

The yield of ragi under different farming practices demonstrated notable differences across treatments (Fig. 1). T_2 achieved the highest yield, with a grain yield of 3086 kg/ha and straw yield of 4533 kg/ha, significantly outperforming other treatments. T_6 performed well, with a grain yield of 2954 kg/ha and straw yield of 4302 kg/ha after T_2. T_4 and T_3 yielding 2874 kg/ha and 2824 kg/ha of grain, respectively, along with straw yields of 4175 kg/ha and 4141 kg/ha. T_7 and T_8, recorded similar results, with grain yields of 2313 kg/ha and 2297 kg/ha, and straw yields of 3925 kg/ha and 3912 kg/ha, respectively. These results highlight RDF and organic farming practices as the most effective strategies for maximizing ragi yield under field conditions.

The increased yield in T_2 resulted from improved crop growth, enabling better nutrient absorption and photosynthate production, which translocated to the sink. Enhanced root growth facilitated greater nutrient uptake from the soil. The integration of inorganic fertilizers, FYM, and biofertilizers improved yield attributes by stimulating microbial activity, promoting bacterial growth, and enhancing root exudate secretion, creating a favourable environment for microbial development, ultimately increasing grain and straw yields in finger millet. Such observations were also recorded by previous researchers like Jat *et al.* (2018) [7], Opera *et al.* (2017) [11] and Kishore *et al.* (2017) [8].

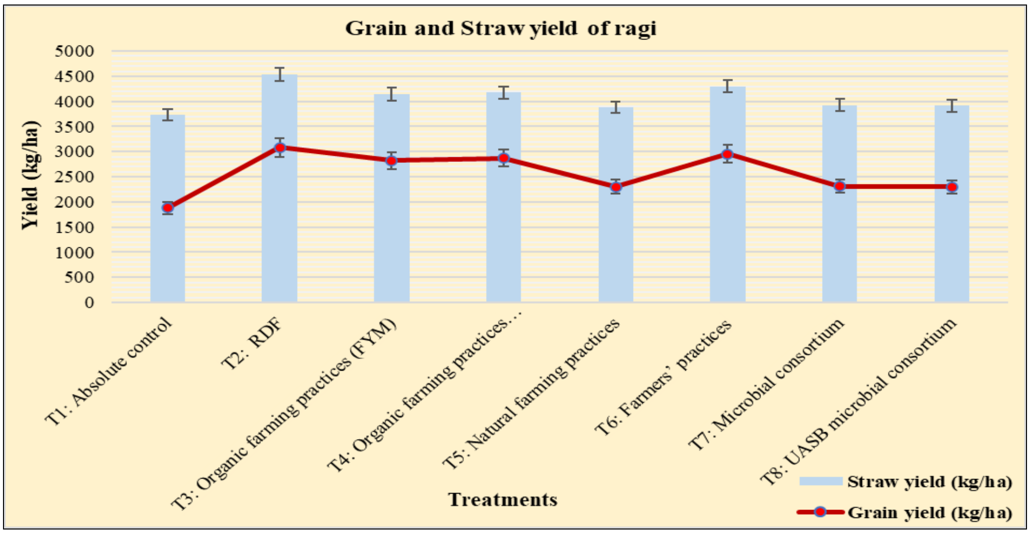

Fig 1: Effect of microbial consortium and different farming practices on yield of ragi under field condition

Soil microbial population

The impact of different farming practices on soil microbial populations in ragi showed significant variations (Table 4). Treatment T_4 recorded the highest bacterial (7.65–7.62 log cfu/g), fungal (4.84–4.68 log cfu/g), and actinomycetes population (3.58–3.48 log cfu/g) across growth stages. T_3 showed similar trends and microbial consortia treatments (T_7, T_8) also enhanced microbial population while T_1 had the lowest counts. These results highlight the benefits of organic and microbial-enhanced practices in improving soil microbial health.

The application of 100% nitrogen equivalent vermicompost and FYM significantly boosts microbial populations in the soil due to its high content of organic matter, essential nutrients, and diverse microbial communities (Das *et al.*, 2019). Vermicompost and FYM acts as both a nutrient source and a microbial inoculant, enriching the soil with beneficial bacteria, fungi, and actinomycetes. This leads to enhanced microbial diversity and activity, which in turn improves nutrient cycling, organic matter decomposition, and overall soil health (Kumar *et al.*, 2022) [9].

Table 4: Effect of microbial consortium and different farming practices on soil microbial population at different growth stages of ragi under field condition

Treatments	Bacteria (log cfu/g soil)			Fungi (log cfu/g soil)			Actinomycetes (log cfu/g soil)		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1: Absolute control	7.14^{d}	7.24^{c}	7.02^{c}	4.04^{e}	4.28^{e}	4.02^{f}	3.17^{e}	3.27^{e}	3.09^{d}
T_2: Recommended dose of fertilizer (RDF)	7.22^{d}	7.51^{b}	7.19^{b}	4.35^{d}	4.54^{c}	4.29^{e}	3.25^{d}	3.36^{d}	3.21^{c}
T_3: Organic farming practices (N equivalent with FYM)	7.61^{a}	7.78^{a}	7.51^{a}	4.79^{a}	4.96^{a}	4.65^{ab}	3.54^{a}	3.62^{ab}	3.45^{a}
T_4: Organic farming practices (N equivalent with vermicompost)	7.65^{a}	7.86^{a}	7.62^{a}	4.84^{a}	4.97^{a}	4.68^{a}	3.58^{a}	3.67^{a}	3.48^{a}
T_5: Natural farming practices	7.25^{cd}	7.48^{b}	7.12^{bc}	4.47^{c}	4.66^{b}	4.41^{d}	3.36^{c}	3.42^{c}	3.36^{b}
T_6: Farmers' practices	7.21^{d}	7.49^{b}	7.21^{b}	4.29^{d}	4.38^{d}	4.26^{e}	3.24^{d}	3.31^{de}	3.16^{c}
T_7: Microbial consortium	7.42^{b}	7.56^{b}	7.16^{b}	4.61^{b}	4.71^{b}	4.58^{b}	3.42^{b}	3.59^{b}	3.43^{a}
T_8: UASB microbial consortium (Reference)	7.36^{bc}	7.48^{b}	7.11^{bc}	4.52^{c}	4.67^{b}	4.49^{c}	3.41^{bc}	3.6^{b}	3.44^{a}

Note: DAS- days after sowing; Mean values followed by the same letter in each column are not significantly different from each other as determined by DMRT ($p<0.05$).

Available nutrient status in soil

The available nutrient status in soil varied across treatments (Table 5). Initially, the available nitrogen, phosphorus and potassium were found to be 192.32 Kg ha^{-1}, 17.14 Kg ha^{-1} and 161.18 Kg ha^{-1} respectively. At harvest, T_4 had the highest nitrogen (219.74 kg ha^{-1}), phosphorus (34.4 kg ha^{-1}), and potassium (186.17 kg ha^{-1}), followed by T_3 and T_2. T_7 improved nutrient availability, with phosphorus at 29.61 kg ha^{-1} and potassium at 174.36 kg ha^{-1}, showing a significant enhancement over T_1, which recorded the lowest nutrient levels. Overall, the organic farming practices, particularly those with vermicompost, had the highest soil nutrient availability, while the absolute control treatment exhibited significantly lower levels of nitrogen, phosphorus, and potassium.

The differences in nutrient availability at harvest highlight the impact of farming practices on soil nutrient dynamics. Vermicompost and FYM enhance microbial activity, improve nutrient cycling, and provide slow-release nutrients, increasing nitrogen, phosphorus, and potassium availability (Shetty and Kumar, 2018) [13]. RDF also showed good nutrient levels due to efficient nutrient supply from synthetic fertilizers, though it may not offer long-term soil health benefits compared to organic amendments (Habtamu *et al.*, 2024) [3].

Table 5: Effect of microbial consortium and different farming practices on soil available nutrients at harvest

Treatments	Available Nitrogen (kg ha^{-1})	Available Phosphorus (kg ha^{-1})	Available Potassium (kg ha^{-1})
T_2: Recommended dose of fertilizer (RDF)	209.15^c	31.37^c	182.04^b
T_3: Organic farming practices (N equivalent with FYM)	212.45^b	32.81^b	185.21^a
T_4: Organic farming practices (N equivalent with vermicompost)	219.74^a	34.4^a	186.17^a
T_5: Natural farming practices	191.24^f	18.07^e	170.82^d
T_6: Farmers' practices	204.57^d	29.61^c	168.71^e
T_7: Microbial consortium	194.68^e	19.59^d	180.13^c
T_8: UASB microbial consortium (Reference)	194.47^e	19.56^d	180.32^c

Note: Mean values followed by the same letter in each column are not significantly different from each other as determined by DMRT ($p<0.05$).

Conclusion

The study demonstrated that microbial consortium application positively influences the growth and yield of ragi under different farming systems by enhancing soil microbial activity and nutrient availability. RDF (Conventional farming) treatment yielded the highest productivity, followed by organic farming with vermicompost and FYM. The microbial consortium significantly improved soil health through increased microbial diversity, facilitating better nutrient cycling. Organic treatments promoted higher microbial activity, reinforcing their role in sustainable agriculture. These results emphasize the potential of microbial consortia as an eco-friendly strategy to improve ragi production while maintaining long-term soil fertility and sustainability.

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