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GROWTH, PRODUCTIVITY, NUTRIENT UPTAKE AND SOIL HEALTH OF ORGANICALLY GROWN FINGER MILLET (*ELEUSINE CORACANA L. GAERTN.*) AS INFLUENCED BY LEGUME INTERCROPPING AND ORGANIC NUTRIENT MANAGEMENT

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ABSTRACT:
A field experiment was conducted during the kharif seasons of 2023 and 2024 to evaluate the effect of legume intercropping and organic nutrient management on growth, yield, nutrient uptake and soil health of finger millet (Eleusine coracana L. Gaertn.). The experiment was laid out in a split-plot design with three cropping systems in the main plots (sole finger millet, finger millet + black gram and finger millet + groundnut) and five organic nutrient management practices in the subplots, in which the recommended dose of nitrogen (RDN) was supplied through farmyard manure (FYM) alone, in combination with vermicompost (VC) or oil cake, and with microbial consortium. Pooled over two years, finger millet intercropped with groundnut recorded the tallest plants, the highest leaf area index (2.52) and dry matter (365.7 g m−2), superior yield attributes and the highest grain yield (2466.8 kg ha−1), which was 65.8% and 25.6% higher than sole finger millet and finger millet + black gram, respectively. Among nutrient sources, 50% RDN through FYM + 50% RDN through VC + microbial consortium (T4) produced the highest grain yield (2161.8 kg ha−1), 22.2% more than 100% RDN through FYM. The finger millet + groundnut system and T4 also recorded the highest total uptake of nitrogen (45.1 and 41.8 kg ha−1), phosphorus (12.6 and 11.7 kg ha−1) and potassium (52.9 and 47.9 kg ha−1), the largest populations of bacteria, fungi and actinomycetes, higher microbial biomass nitrogen, and higher post-harvest available phosphorus and potassium. Finger millet + groundnut intercropping combined with FYM, vermicompost and a microbial consortium is therefore recommended for higher productivity and improved soil health of organically grown finger millet.

KEYWORDS: Black gram, Finger millet, Groundnut, , Intercropping, Microbial consortium, Organic nutrient management, Soil health, Vermicompost.

1. INTRODUCTION

Finger millet (Eleusine coracana L. Gaertn.) is a hardy, climate-resilient cereal grown mainly by small and marginal farmers in rainfed uplands. It is the most productive of the small millets in India and accounts for nearly 85% of their production (Sakamma et al., 2018). The grain is rich in calcium, iron, dietary fibre and essential amino acids and is gluten-

free, which makes it valuable in combating micronutrient malnutrition or hidden hunger (Muthayya et al., 2013). In Odisha, however, the productivity of finger millet (767 kg ha−1) is far below the national average of 1747 kg ha−1 (Millet Stats, 2023), mainly because the crop is grown on marginal, acidic and nutrient-poor uplands with little or no use of manures and fertilizers.

Intercropping grains and legumes is a well-established approach for increasing yield and stability in rainfed environments. Component crops with different canopy structures, rooting depths, and durations exploit light, water, and nutrients in complementary ways, allowing the system to produce more per unit area than single crops (Mead and Willey, 1980; Bantie et al., 2014). Legumes fix atmospheric nitrogen, which is then available to the companion cereal, and cereal-legume partnerships boost phosphorus, iron, and zinc uptake via rhizosphere interactions (Xue et al., 2016; Maitra et al., 2020). Recent research on red soils in southern India have demonstrated that finger millet intercropped with groundnut yields land equivalent ratios of 1.54-1.64 and higher net returns (Sukanya et al., 2024; Shilpa et al., 2025).

Organic nutrient management is gaining popularity for producing healthy food while improving soil health. Farmyard manure (FYM), vermicompost, and oil cakes provide major and micronutrients gradually, improve soil physical qualities, and promote microbial activity (Naik et al., 2017; Olle, 2019). Gawade et al. (2013) found that using poultry manure, FYM, and vermicompost at equal nitrogen rates resulted in grain yields ranging from 1740 to 2211 kg ha−1. Microbial consortia containing nitrogen-fixing and nutrient-solubilizing organisms can improve the efficacy of organic sources. However, there is limited information on the combined effect of legume intercropping and organic nutrient sources, applied alone or with a microbial consortium, on finger millet development, yield, nutrient uptake, and soil biological and chemical features, particularly in Odisha's acidic soils.The present study was therefore undertaken to evaluate these practices in an organically managed finger millet–legume intercropping system.

2. METHODOLOGY

2.1 Experimental site and soil

The field experiment was conducted during the kharif seasons of 2023 and 2024 at the research farm of Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India. The geographical location of Bhubaneswar is situated between 20o15'N latitude, 85o52'E longitude and at an altitude of 25.9 m above mean sea level and about 64km away from the Bay of Bengal, Odisha. The soil of the experimental field was sandy loam in texture, acidic in reaction (pH 5.88) and non-saline (EC 0.052 dS m−1), with 5.02 g kg−1 organic carbon, 230.62 kg ha−1 available nitrogen, 17.56 kg ha−1 available phosphorus and 148.29 kg ha−1 available potassium. The initial populations of bacteria, fungi and actinomycetes were 13.2 × 106, 10.1 × 104 and 13.3 × 105 cfu g−1 soil, respectively, and initial microbial biomass carbon (MBC) and nitrogen (MBN) were 215.8 µg C g−1 and 14.6 µg N g−1 soil.

2.2 Experimental design and treatments

The experiment was laid in a split-plot design with three replicates. The main plots used three cropping systems: M1-sole finger millet, M2-finger millet + black gram (5:2), and M3-finger millet + groundnut (5:2). The subplots consisted of five organic nutrient management practices: T1-100% RDN through FYM; T2-50% RDN through FYM + 50% RDN through vermicompost (VC); T3-50% RDN through FYM + 50% RDN through neem oil cake; T4-T2 + microbial consortia; and T5-T3 + microbial consortium. The recommended nitrogen dose (RDN) was 60 kg N ha−1, and manure quantities were estimated based on nitrogen content. The microbial consortium was applied as per treatment. Arjuna variety of finger millet was transplanted at [15cm x 10cm], and black gram (Sashi) and groundnut (Dharani) were sown as per the intercropping arrangement. No chemical fertilizers or synthetic plant protection chemicals were used.

2.3 Observations

Plant height, number of tillers, dry matter accumulation, and leaf area index (LAI) of finger millet were measured 90 days after transplantation. At harvest, we recorded the number of earheads, fingers, spikelets, grains, finger length, and 1000-grain weight. We also calculated grain and straw yields based on the net plot area. The harvest index was derived as grain yield / (grain yield + straw yield) × 100.

Soil samples collected after harvest were tested for pH (1:2.5 soil:water) and electrical conductivity (Jackson, 1973), organic carbon by the wet oxidation method (Walkley and Black, 1934), available nitrogen by the alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus by Bray's No. 1 method (Bray and Kurtz, 1945), and available potassium by the neutral normal ammonium acetate method using a flame photometer (Jackson, 1973). Bacteria, fungi, and actinomycetes were counted using the serial dilution plate count method on selective medium (Wollum, 1982), while MBC and MBN were estimated using the chloroform fumigation-extraction method (Vance et al., 1987; Brookes et al., 1985). Grain and straw samples were analysed for nitrogen, phosphorus and potassium (Piper, 1966; Jackson, 1973), and nutrient uptake was calculated by multiplying nutrient concentration by the corresponding dry matter yield.

2.4 Statistical analysis

Data were analysed for variance using a split-plot design, and a two-year pooled analysis was performed in accordance with Gomez and Gomez (1984). Treatment means were compared using the crucial difference (CD) at the 5% level of confidence.

3. RESULTS AND DISCUSSION

3.1 Growth parameters

Intercropping and nutrient management had a substantial impact on all finger millet growth metrics at 90 days after planting (Table 1). Finger millet intercropped with groundnut (M3) had the highest plant height (103.85 cm), number of

tillers (148.7 m−2), dry matter accumulation (365.7 g m−2), and LAI (2.52), followed by finger millet + black gram (M2). Sole finger millet (M1) had the lowest results. Compared to the single crop, M3 enhanced plant height by 11.7%, tillers by 11.2%, dry matter by 7.2%, and LAI by 15.6% (Fig. 1). Among the nutrient management practices, T4 (50% RDN through FYM + 50% RDN through VC + microbial consortium) produced the highest values of all growth parameters, which were significantly superior to the other treatments, followed by T2 and T5, while T1 produced the lowest values.

Table 1. Effect of intercropping and organic nutrient management on growth parameters of finger millet at 90 DAT (pooled data of 2023 and 2024)

Treatment	Plant height (cm)	Tillers (m^{-2})	Dry matter (g m^{-2})	Leaf area index
Cropping system (main plot)				
M_1: Sole finger millet	93.01	133.7	341.2	2.18
M_2: Finger millet + black gram	98.45	140.6	353.4	2.32
M_3: Finger millet + groundnut	103.85	148.7	365.7	2.52
SEm (±)	1.408	0.811	2.062	0.013
CD (p = 0.05)	4.590	2.646	6.723	0.041
Nutrient management (subplot)				
T_1: 100% RDN (FYM)	94.51	135.4	344.3	2.27
T_2: 50% RDN (FYM) + 50% RDN (VC)	99.56	142.5	357.3	2.48
T_3: 50% RDN (FYM) + 50% RDN (oil cake)	96.55	137.5	348.5	2.32
T_4: T_2 + microbial consortium	102.47	148.0	362.9	2.61
T_5: T_3 + microbial consortium	99.11	141.4	354.0	2.45
SEm (±)	0.93	1.58	1.71	0.041
CD (p = 0.05)	2.88	4.50	4.90	0.116

DAT, days after transplanting; FYM, farmyard manure; RDN, recommended dose of nitrogen; VC, vermicompost.

The improved growth of finger millet in association with legumes can be due to the transfer of biologically fixed nitrogen from the legume, as well as increased availability of phosphate and micronutrients in the shared rhizosphere (Xue et al., 2016; Maitra et al., 2020). Groundnut, with its higher biomass and nodulation, is expected to have contributed more nitrogen than black gram. The superiority of T4 is due to the faster mineralisation of nutrients from vermicompost, which is high in plant-available nutrients and growth-promoting compounds (Olle, 2019), as well as the consistent release of nutrients from FYM and the activity of the microbial consortium.

3.2 Yield attributes and yield

All yield parameters were significantly greater during intercropping compared to solitary cropping (Table 2). Finger millet + groundnut had the maximum number of earheads (6.14), fingers (6.45), spikelets (76.7), grains (5.41), finger length (8.47 cm), and 1000-grain weight (3.51 g), reflecting increases of 7.3-66.4% over solitary finger millet (Fig. 1). Among the nutrient management approaches, T4 had the greatest values for all yield qualities and was significantly superior than the other treatments, followed by T2. T1 had the lowest values. T4 resulted in significant relative gains in fingers ear−1 (48.9%) and spikelets finger−1 (31.9%).

Table 2. Effect of intercropping and organic nutrient management on yield attributes and yield of finger millet (pooled data of 2023 and 2024)

Treatment	Earheads hill−1	Fingers ear−1	Spikelets finger−1	Grains spikelet−1	Finger length (cm)	1000-grain wt (g)	Grain yield (kg ha−1)	Straw yield (kg ha−1)	HI (%)
Cropping system (main plot)									
M1: Sole finger millet	3.69	5.00	62.5	4.28	7.18	3.27	1487.8	2639.1	35.5
M2: Finger millet + black gram	5.08	5.87	68.8	4.82	7.83	3.37	1964.1	2757.6	41.5
M3: Finger millet + groundnut	6.14	6.45	76.7	5.41	8.47	3.51	2466.8	2887.1	46.1
SEm (±)	0.027	0.037	0.402	0.027	0.045	0.019	11.10	15.61	0.234
CD (p = 0.05)	0.089	0.121	1.309	0.088	0.148	0.064	36.20	50.91	0.918
Nutrient management (subplot)									
T1: 100% RDN (FYM)	4.42	4.7	59.3	4.52	7.03	3.21	1769.1	2671.9	39.8
T2: 50% RDN (FYM) + 50% RDN (VC)	5.18	6.1	73.3	4.95	8.00	3.48	2059.5	2792.4	42.4
T3: 50% RDN (FYM) + 50% RDN (oil cake)	4.72	5.0	65.4	4.73	7.71	3.29	1885.3	2724.1	40.9
T4: T2 + microbial consortium	5.55	7.0	78.2	5.14	8.44	3.56	2161.8	2839.8	43.2
T5: T3 + microbial consortium	4.99	5.9	70.4	4.87	7.97	3.37	1988.9	2778.1	41.7
SEm (±)	0.093	0.125	1.317	0.041	0.086	0.024	34.94	51.30	0.392
CD (p = 0.05)	0.264	0.354	3.744	0.120	0.250	0.070	101.28	50.91†	1.143

Finger millet grain yield showed a similar pattern (Fig. 2). Finger millet + groundnut had the largest grain yield (2466.8 kg ha−1), surpassing solitary finger millet (1487.8 kg ha−1) and finger millet + black gram (1964.1 kg ha−1) by 65.8% and 25.6%, respectively. Straw yields varied from 2639.1 kg ha−1 for solitary finger millet to 2887.1 kg ha−1 for M3. T4 had the highest grain yield (2161.8 kg ha−1), surpassing all other treatments and 22.2% higher than T1 (1769.1 kg ha−1). T2 (2059.5 kg ha−1) and T5 (1988.9 kg ha−1) were comparable, while T3 (1885.3 kg ha−1) outperformed T1. The maximum straw yield was achieved with T4 (2839.8 kg ha−1) and T2 (2792.4 kg ha−1). The harvest index was greater under intercropping (41.6-46.1%) than under solo cropping (36.1%), and it was maximum under T4 (43.2%), showing that the treatments increased dry matter partitioning into grain.



Fig. 1. Percentage increase in growth parameters, yield attributes and yield of finger millet under intercropping (relative to sole finger millet, M1) and organic nutrient management (relative to 100% RDN through FYM, T1). Calculated from pooled means in Tables 1 and 2.

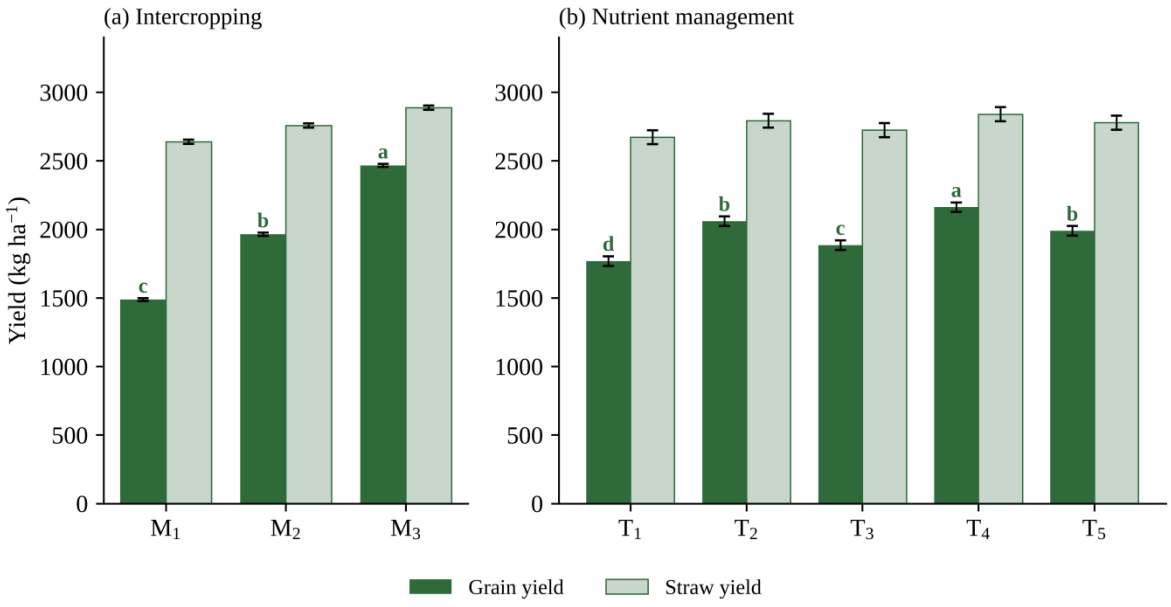

Fig. 2. Grain and straw yield of finger millet as influenced by (a) intercropping and (b) organic nutrient management (pooled data of 2023 and 2024). Error bars show SEm; bars of grain yield with the same letter do not differ significantly at p = 0.05 (CD test). M1, sole finger millet; M2, finger millet + black gram; M3, finger millet + groundnut; T1–T5 as in Table 1.

The increased yield from intercropping was due to improved growth and yield characteristics, which were caused by better nutrient delivery and resource use. Complementary resource usage and nitrogen transfer from legumes have been shown to improve the productivity of finger millet-based intercropping systems on red soils (Sukanya et al., 2024; Shilpa et al., 2025). The combined application of FYM and vermicompost containing beneficial microorganisms synchronises nutrient release with crop demand, explaining the higher yield under T4; similar yield advantages from organic manures in finger

millet have been observed by Gawade et al. (2013) and Naik et al. (2017). Vermicompost-based treatments (T2, T4) consistently outperformed oil cake-based treatments (T3, T5), and the microbial consortium boosted yield from both sources.

3.3 Soil microbial parameters

Intercropping and nutrient management had a substantial impact on bacteria, fungus, and actinomycetes populations, as well as MBN, following harvest (Table 3). Finger millet + groundnut had higher populations of bacteria (21.33 × 106 cfu g−1), fungi (14.11 × 104 cfu g−1), and actinomycetes (18.48 × 105 cfu g−1), as well as the highest MBN (19.38 µg N g−1) compared to solitary finger millet, with increases of 22.1%, 21.2%, 27.7%, and 25.7%, respectively. MBC did not differ significantly across cropping systems (213.57-217.92 µg C g−1). T4 had the greatest microbial population (MBC) (227.60 µg C g−1) MBN (18.80 µg N g−1) was comparable to T2 and T5, while T1 showed the lowest values. Bacterial populations grew by 32-62% and MBN by 6-33%, although MBC decreased somewhat under T1 and T3 (Fig. 3).

Table 3. Effect of intercropping and organic nutrient management on soil microbial parameters after harvest of finger millet (pooled data of 2023 and 2024)

Treatment	Bacteria (×106 cfu g−1)	Fungi (×104 cfu g−1)	Actinomycetes (×105 cfu g−1)	MBC (µg C g−1)	MBN (µg N g−1)
Cropping system (main plot)					
M1: Sole finger millet	17.47	11.64	14.47	213.57	15.42
M2: Finger millet + black gram	19.70	12.66	16.36	215.54	17.60
M3: Finger millet + groundnut	21.33	14.11	18.48	217.92	19.38
SEm (±)	0.156	0.098	0.129	1.644	0.146
CD (p = 0.05)	0.611	0.386	0.507	6.455	0.573
Nutrient management (subplot)					
T1: 100% RDN (FYM)	17.91	11.94	14.93	198.41	15.85
T2: 50% RDN (FYM) + 50% RDN (VC)	20.48	13.33	17.27	224.97	18.37
T3: 50% RDN (FYM) + 50% RDN (oil cake)	18.34	12.09	15.45	204.59	16.43
T4: T2 + microbial consortium	20.79	13.57	17.63	227.60	18.80
T5: T3 + microbial consortium	19.97	13.10	16.90	222.80	17.90
SEm (±)	0.53	0.344	0.443	5.668	0.474
CD (p = 0.05)	1.56	1.005	1.292	16.540	1.382
Initial value	13.2	10.1	13.3	215.8	14.6

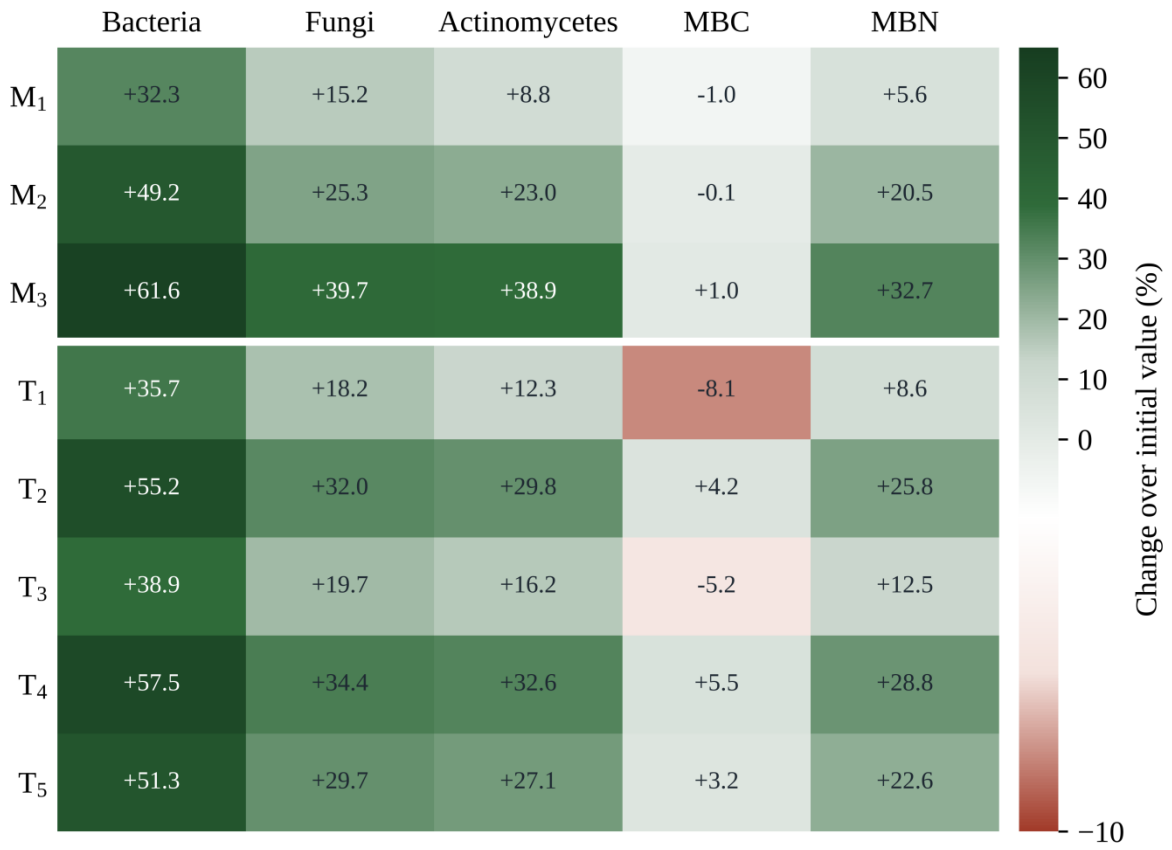

Fig. 3. Change (%) in soil microbial populations, microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) after harvest relative to initial values, under intercropping (M1–M3) and organic nutrient management (T1–T5).

The stimulation of soil microorganisms by legume intercropping can be attributed to increased root biomass, nitrogen-rich root exudates, and legume wastes, which provide readily available carbon and nitrogen to soil microbes (Xue et al., 2016). Vermicompost contains a large number of beneficial microbes and humified organic matter (Olle, 2019), and the inclusion of a microbial consortium expanded the microbial pool, explaining the greater microbial biomass at T2, T4, and T5.

3.4 Soil chemical properties

The treatments had a considerable impact on the nutrients available after harvest (Table 4). Finger millet + groundnut had the highest accessible nitrogen (267.08 kg ha−1), phosphorus (18.74 kg ha−1), and potassium (150.88 kg ha−1), followed by finger millet + black gram, with solitary finger millet having the lowest values. Organic carbon was substantially higher under M3 (5.22 g kg−1) than under M1 (4.86 g kg−1), while soil pH did not differ significantly between cropping systems. T4 had the highest available nitrogen (253.87 kg ha−1), phosphorus (17.40 kg ha−1), and potassium (148.08 kg ha−1), comparable to T2 for nitrogen and T2 and T5 for phosphorus. Nutrient management had no significant effect on organic carbon or pH. Available phosphorus and potassium levels were kept close to or above their original values in M3 and T4, but decreased in solitary finger millet and T1.

Table 4. Effect of intercropping and organic nutrient management on post-harvest soil available nutrients, EC, organic carbon and pH (pooled data of 2023 and 2024)

Treatment	Available N (kg ha−1)	Available P (kg ha−1)	Available K (kg ha−1)	EC (dS m−1)	OC (g kg−1)	pH
Cropping system (main plot)						
M1: Sole finger millet	223.83	13.62	133.62	0.04	4.86	5.94
M2: Finger millet + black gram	245.41	16.20	142.16	0.05	5.03	5.98
M3: Finger millet + groundnut	267.08	18.74	150.88	0.06	5.22	6.05

Treatment	Available N (kg ha−1)	Available P (kg ha−1)	Available K (kg ha−1)	EC (dS m−1)	OC (g kg−1)	pH
SEm (±)	1.95	0.128	1.157	0.000	0.040	0.040
CD (p = 0.05)	7.66	0.508	4.541	0.001	0.158	0.159
Nutrient management (subplot)						
T1: 100% RDN (FYM)	238.29	14.53	130.20	0.04	4.97	5.95
T2: 50% RDN (FYM) + 50% RDN (VC)	248.83	16.86	146.14	0.05	5.06	6.01
T3: 50% RDN (FYM) + 50% RDN (oil cake)	241.11	15.85	142.45	0.05	5.00	5.99
T4: T2 + microbial consortium	253.87	17.40	148.08	0.06	5.09	6.05
T5: T3 + microbial consortium	245.11	16.30	144.24	0.05	5.06	5.96
SEm (±)	6.44	0.431	3.790	0.001	0.132	0.161
CD (p = 0.05)	18.81	1.259	11.062	0.004	0.386	0.470
Initial value	230.62	17.56	148.29	0.052	5.02	5.88

EC-electrical conductivity; OC, organic carbon.

Legumes increase soil nitrogen by biological fixation and the breakdown of nodules, roots, and leaf litter, and they mobilise sparingly soluble phosphorus by releasing organic acids in the rhizosphere (Xue et al., 2016; Maitra et al., 2020). Vermicompost and microbial inoculants speed up the mineralisation of organic nutrients, resulting in increased nutrient availability under T2 and T4. The minor changes in organic carbon and pH over two seasons suggest that longer-term studies are needed to determine the cumulative impacts of organic management on soil organic matter.

3.5 Nutrient uptake

Intercropping and nutrient management had a considerable influence on grain and straw nitrogen, phosphorus, and potassium uptake (Table 5). Fig. 4 shows that finger millet + groundnut had the highest total uptake of nitrogen (45.07 kg ha−1), phosphorus (12.64 kg ha−1), and potassium (52.86 kg ha−1), which was 65.6%, 55.1%, and 56.9% greater than solitary finger millet. T4 had the highest total uptake of nitrogen (41.81 kg ha−1), phosphorus (11.71 kg ha−1), and potassium (47.90 kg ha−1), followed by T2. T4 significantly increased grain and straw nitrogen and potassium uptake compared to other treatments, while phosphorus uptake was comparable to T2.

Table 5. Effect of intercropping and organic nutrient management on nitrogen, phosphorus and potassium uptake (kg ha−1) by finger millet.

Treatment	N grain	N straw	P grain	P straw	K grain	K straw
Cropping system (main plot)						
M1: Sole finger millet	17.95	9.27	4.49	3.66	8.69	25.00
M2: Finger millet + black gram	24.14	11.74	5.92	4.68	11.38	31.17
M3: Finger millet + groundnut	30.78	14.29	7.15	5.49	14.81	38.05
SEm (±)	0.202	0.093	0.048	0.039	0.097	0.252
CD (p = 0.05)	0.791	0.365	0.190	0.152	0.379	0.991
Nutrient management (subplot)						
T1: 100% RDN (FYM)	21.23	10.21	5.16	4.17	10.12	28.79

Treatment	N grain	N straw	P grain	P straw	K grain	K straw
T2: 50% RDN (FYM) + 50% RDN (VC)	25.93	12.56	6.15	4.82	12.18	32.17
T3: 50% RDN (FYM) + 50% RDN (oil cake)	22.10	10.68	5.45	4.28	10.80	29.41
T4: T2 + microbial consortium	28.13	13.68	6.58	5.13	13.20	34.70
T5: T3 + microbial consortium	24.07	11.70	5.93	4.65	11.86	31.98
SEm (±)	0.620	0.311	0.158	0.123	0.323	0.845
CD (p = 0.05)	1.809	0.908	0.461	0.358	0.941	2.465

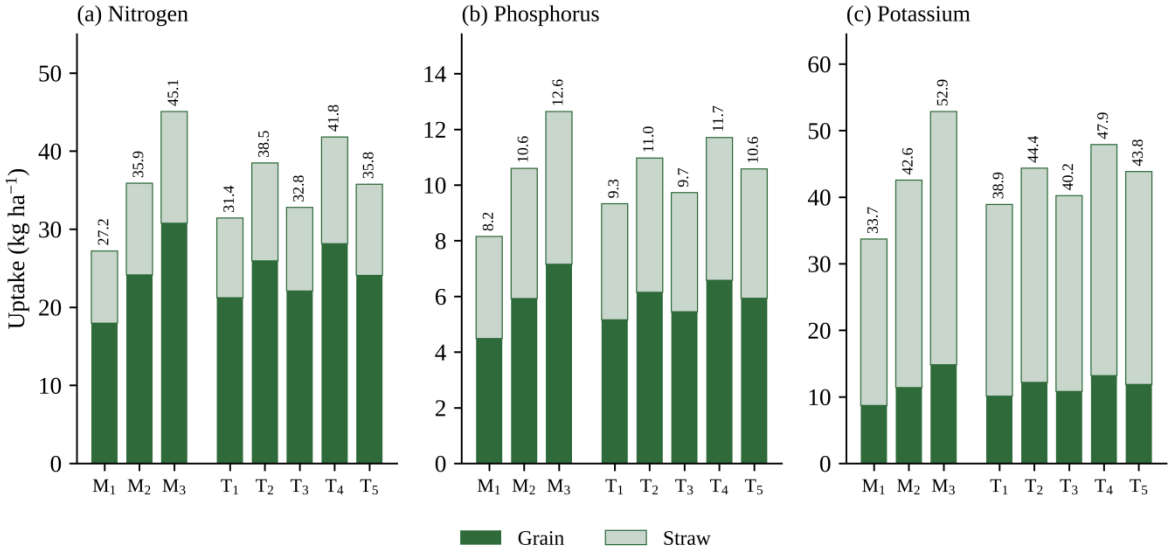

Fig. 4. Total uptake of (a) nitrogen, (b) phosphorus and (c) potassium by grain and straw of finger millet under intercropping (M1–M3) and organic nutrient management (T1–T5). Values above bars are total uptake (kg ha−1).

Nutrient intake depends on nutrient concentration and dry matter generation. The enhanced uptake in M3 and T4 treatments indicates both better grain and straw yields and increased nutrient availability in the soil. Finger millet benefited from improved nitrogen delivery from the legume, phosphorus solubilisation by microorganisms, and the balanced, prolonged release of nutrients from combined organic sources (Naik et al., 2017; Shilpa et al., 2025).

4. CONCLUSION

Intercropping finger millet with groundnut significantly increased finger millet growth, yield characteristics, grain yield, and nutrient uptake while also increasing soil microbial populations and post-harvest nutrient availability when compared to solitary finger millet and finger millet + black gram. Among organic nutrient management approaches, the application of 50% RDN via FYM and 50% RDN via vermicompost, combined with a microbial consortium, resulted in the maximum grain yield, nutrient uptake, and soil biological activity. Finger millet and groundnut intercropping with FYM, vermicompost, and a microbial consortium is thus advised for increased productivity and soil health in organically farmed finger millet. These recommendations would be strengthened further by evaluating system productivity, economics, and long-term soil changes across multiple seasons.

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